Accident- Tank Farm explosion and fire in Deer Park, Texas

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ABBREVIATIONS

ACC	American Chemistry Council
AIChE	American Institute of Chemical Engineers
ANSI	American National Standards Institute
CAA	Clean Air Act
API	American Petroleum Institute
BPH	barrels per hour
CCPS	Center for Chemical Process Safety
C.F.R.	Code of Federal Regulations
CCR	central control room
CIMA	Channel Industries Mutual Aid
CSB	U.S. Chemical Safety and Hazard Investigation Board
CTEH	Center for Toxicology and Environmental Health, LLC
DCS	distributed control system
EBV	emergency block valves
EPA	U.S. Environmental Protection Agency
ERT	Emergency Response Team
HSE	Health and Safety Executive
HCFMO	Harris County Fire Marshal’s Office
IOM	Installation, Operation, and Maintenance
ISD	Independent School District
ITC	Intercontinental Terminals Company, LLC
LEL	lower explosive limit

LPG	liquified petroleum gas
MOC	management of change
MOV	Motor operated valve
NFPA	National Fire Protection Association
OSHA	Occupational Safety and Health Administration
PM	Preventative Maintenance
PHA	Process Hazard Analysis
PSI	pounds per square inch
PSM	Process Safety Management
PSSR	pre-startup safety review
Pygas	pyrolysis gasoline
RBPS	Risk Based Process Safety
RAGAGEP	Recognized and Generally Accepted Good Engineering Practices
RMP	Risk Management Program
ROEIV	remotely operated emergency isolation valves
SDS	Safety Data Sheet
SPCC	Spill Prevention Control and Countermeasure Plan
TACB	Texas Air Control Board
TCEQ	Texas Commission on Environmental Quality
USCG	United States Coast Guard
VOCs	volatile organic compounds

EXECUTIVE SUMMARY

On Sunday, March 17, 2019, a large fire erupted at the Intercontinental Terminals Company, LLC (ITC) bulk liquid storage terminal located in Deer Park, Texas. The fire originated in the vicinity of Tank 80-8, an 80,000-barrel aboveground atmospheric storage tank that held a blend of naphtha and butane product, a flammable liquid. Once the fire erupted, ITC was unable to isolate or stop the release. As a result, the fire burned, intensified, and spread to the other 14 tanks located in the same containment area. The fire burned for three days, until it finally was extinguished on Wednesday, March 20, 2019. The fire caused substantial property damage at the ITC Deer Park terminal, including the destruction of fifteen (15) 80,000-barrel aboveground atmospheric storage tanks and their contents.

The incident also significantly impacted the environment. A containment wall around the tanks breached and released an estimated 470,000–523,000 barrels of hydrocarbon and petrochemical products, firefighting aqueous film forming foam, and contaminated water into Tucker Bayou and adjacent water, sediments, and habitats. From there, the released materials flowed into Buffalo Bayou and were carried out by streamflow and tides into the Houston Ship Channel and surrounding waters. A seven-mile stretch of the Houston Ship Channel adjacent to the ITC Deer Park terminal was closed, as were several waterfront parks in Harris County and the City of LaPorte, due to the contamination.

The incident did not result in any injuries or fatalities; however, the local community experienced serious disruptions, including several shelter-in-place orders because of benzene-related air quality concerns. A shelter-in-place was issued for the entire City of Deer Park at one point, and local schools and businesses either closed or operated under modified conditions. A portion of a major highway in the area also was closed. ITC estimated that property damage resulting from the loss of the First & Second 80's tank farm associated with the March 17, 2019, incident exceeded $150 million.

SAFETY ISSUES

The U.S. Chemical Safety and Hazard Investigation Board's (CSB's) investigation identified the safety issues below.

- **Pump Mechanical Integrity.** ITC did not have a formal mechanical integrity procedure in place that defined requirements for maintaining the mechanical integrity of Tank 80-8 and its associated equipment, including the Tank 80-8 circulation pump. A formal mechanical integrity program for pumps in highly hazardous chemical service could have prevented this incident by providing ITC with additional opportunities to identify pump issues prior to the incident. The mechanical seal on the pump failed on March 17, 2019, allowing butane-enriched naphtha product to release from the pump while it continued to operate. (Section 4.1)

- **Flammable Gas Detection Systems.** Tank 80-8 was not equipped with a flammable gas detection system to warn personnel of a hazardous atmosphere resulting from loss of containment from the tank or its associated equipment. In 2014, a hazard review team recommended the addition of flammable gas detection systems near Tank 80-8; however, ITC did not implement this recommendation, and did not document why it was not implemented. In the absence of a flammable gas detection system, there were no alarms to alert personnel about the initial release of butane-enriched naphtha product around the Tank 80-8 piping manifold. Consequently, the butane-enriched naphtha product continued to release from the failed pump for approximately 30 minutes, completely undetected, before its flammable vapors eventually ignited. (Section 4.2)

- **Remotely Operated Emergency Isolation Valves.** Tank 80-8 and the other aboveground storage tanks located in the First & Second 80's tank farm were not equipped with remotely operated emergency isolation valves (ROEIVs) designed to mitigate process releases remotely from a safe location. The primary drivers for identifying the need for this type of equipment would have been through implementation of hazard assessments, such as those required by the Occupational Safety and Health Administration (OSHA) Process Safety Management (PSM) standard and the U.S. Environmental Protection Agency (EPA) Risk Management Program (RMP) rule, as well as insurance company audits and/or corporate risk evaluations results. On the day of the incident, the large volume of butane-enriched naphtha product contained in Tank 80-8 could not be remotely or automatically isolated, and it continued to release, via the failed pump, fueling the fire that continued to intensify around the tank. As the Tank 80-8 fire intensified, flames from the fire spread to adjacent tank piping manifolds in the tank farm and eventually compromised the equipment, causing breaches in piping that allowed the hydrocarbon and petrochemical products contained in the storage tanks to release into the common containment area. (Section 4.3)

- **Tank Farm Design.** Although the First & Second 80's tank farm was designed largely in accordance with applicable National Fire Protection Association (NFPA) 30 requirements, elements of the tank farm design, including tank spacing, subdivisions, engineering controls for pumps located inside the containment area, and drainage systems, made it difficult for emergency responders to slow or prevent the spread of the initial fire and allowed the fire to spread to other tanks within the tank farm. While NFPA 30 defines minimum requirements for tank farm design, additional industry guidance documents provide more robust tank farm design recommendations. While ITC was not required to implement additional industry guidance recommendations, many of which were developed after construction of the First & Second 80's tank farm, implementation of such recommendations could have prevented the escalation of this incident. (Section 4.4)

- **PSM and RMP Applicability.** ITC did not apply a formal process safety management program to Tank 80-8 because neither the OSHA PSM standard nor the EPA RMP rule applied to Tank 80-8 and its associated equipment. Tank 80-8 was not covered by the OSHA PSM standard due to the atmospheric storage tank exemption in the standard, and the EPA RMP rule did not apply due to the flammability rating exemption in the rule for the butane-enriched naphtha mixture. Although ITC applied some process safety management elements across the terminal, the company did not apply other key elements, such as Mechanical Integrity and Process Hazard Analysis, to atmospheric storage tanks in highly hazardous chemical service. Applying these elements would have provided the company with additional opportunities to identify and control hazards through multiple layers of protection, including the examples of preventative and mitigative safeguards discussed in this report. Thus, had ITC developed and implemented a comprehensive process safety management program that effectively identified and controlled hazards for Tank 80-8 and its related equipment, the incident could have been prevented. (Section 4.5)

CAUSE

The CSB determined that the cause of the incident was the release of flammable butane-enriched naphtha vapor from the failed Tank 80-8 circulation pump, which accumulated in the area and ignited, resulting in a fire. Contributing to the severity of the incident were the absence of a flammable gas detection system to alert the operators to the flammable mixture before it ignited approximately 30 minutes after the release began, and the absence of remotely operated emergency isolation valves (ROEIVs) to safely secure the flammable liquids in Tank 80-8 and the surrounding tanks in the First & Second 80's tank farm.

Elements of the tank farm design, including tank spacing, subdivisions, engineering controls for pumps located inside the containment area, and drainage systems also contributed to the severity of the incident by allowing the fire to spread to other tanks within the tank farm. The resulting accumulation of hydrocarbon and petrochemical products, firefighting foam, and contaminated water in the secondary containment area ultimately contributed to a breach of the containment wall and a release of materials to the local waterways.

Finally, the CSB determined that because of the atmospheric storage tank exemption contained in the OSHA PSM standard and the flammability exemption contained in the EPA RMP rule, ITC was not required to develop and implement a formal PSM program for Tank 80-8 and its associated equipment that could have provided a process to identify and control the specific hazards that resulted in this incident, which also contributed to this incident.

RECOMMENDATIONS

To Intercontinental Terminals Company, LLC (ITC)

2019-01-I-TX-R1

Develop and implement a process safety management system for the ITC Deer Park terminal applicable to all atmospheric storage tanks and associated equipment in highly hazardous chemical service.[a] The program should follow industry guidance provided in publications such as the American Petroleum Industry's API STD 2610, *Design, Construction, Operation, Maintenance, and Inspection of Terminal and Tank Facilities* and the Center for Chemical Process Safety's *Guidelines for Risk Based Process Safety*.

2019-01-I-TX-R2

Develop and implement a condition monitoring program for all pumps in highly hazardous chemical service at the ITC Deer Park terminal. Ensure that condition monitoring equipment is programmed with control limits, including but not limited to vibration, consistent with ANSI/HI 9.6.9.-2018, that trigger alarms when control limits are exceeded, and that operating procedures and training reflect the appropriate actions to take when an alarm is triggered.

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[a] The OSHA PSM standard defines "highly hazardous chemical" as "a substance possessing toxic, reactive, flammable, or explosive properties…" 29 C.F.R. § 1910.119(b).

2019-01-I-TX-R3

Install flammable gas detection systems with associated alarm functions in product storage and transfer areas at the ITC Deer Park terminal where flammable substance releases could occur. Develop and implement a response plan and operator training for actions to take when an alarm sounds.

2019-01-I-TX-R4

Install remotely operated emergency isolation valves configured to "Fail-Closed" for all atmospheric storage tanks that contain highly hazardous chemicals or liquids with a flammability rating of NFPA-3 or higher at the ITC Deer Park terminal.

2019-01-I-TX-R5

Conduct an evaluation of the design of all new and existing tank farms at the ITC Deer Park terminal against the applicable sections of the Third Edition of API STD 2610, *Design, Construction, Operation, Maintenance, and Inspection of Terminal and Tank Facilities* and the 2021 Edition of NFPA 30, *Flammable and Combustible Liquids Code*. At a minimum the evaluation should include, but is not limited to the following sections of API STD 2610:

Section 4	Site Selection and Spacing Requirements
Section 7	Fire Prevention and Protection
Section 8.1	Aboveground Petroleum Storage Tanks
Section 9	Dikes and Berms
Section 10	Pipe, Valves, Pumps, and Piping Systems
Section 11	Loading, Unloading, and Product Transfer Facilities

and the following chapters of NFPA 30:

Chapter 21	Storage of Ignitible (Flammable or Combustible) Liquids in Tanks – Requirements for All Storage Tanks and
Chapter 22	Storage of Ignitible (Flammable or Combustible) Liquids in Tanks – Aboveground Storage Tanks

The evaluation should identify additional engineering controls needed to address minimal tank spacing, subdivisions between tanks, and placement of process equipment in containment areas. In addition, the evaluation should assess the adequacy of the containment wall and drainage system designs, accounting for the impact of firefighting activities, including the application of firewater and foam on these systems. Develop and implement recommendations based on findings from the evaluation.

To American Petroleum Institute (API)

2019-01-I-TX-R6

Update API STD 2610, *Design, Construction, Operation, Maintenance, and Inspection of Terminal and Tank Facilities,* or other appropriate products to include flammable gas detection systems within the leak detection section or where appropriate. The discussion of flammable gas and/or leak detection should address both engineering and administrative controls, including actions associated with responding to a catastrophic or emergency leak.

To Occupational Safety and Health Administration (OSHA)

2019-01-I-TX-R7

(Supersedes ***2001-05-I-DE-R1*** *from Motiva and* ***2010-02-I-PR-R4*** *from CAPECO)*[a]

Eliminate the atmospheric storage tank exemption from the PSM standard.

To Environmental Protection Agency (EPA)

2019-01-I-TX-R8

(Supersedes ***2010-02-I-PR-R1*** *from CAPECO)*

Modify 40 C.F.R. § 68.115(b)(2)(i) to expand coverage of the RMP rule to include all flammable liquids, including mixtures, with a flammability rating of NFPA-3 or higher.

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[a] Previous CSB investigations: Motiva Enterprises Sulfuric Acid Tank Explosion [44] and CSB Caribbean Petroleum Refining Tank Explosion and Fire [46]

1 BACKGROUND

1.1 INTERCONTINENTAL TERMINALS COMPANY, LLC (ITC) COMPANY

At the time of the incident, Intercontinental Terminals Company, LLC (ITC), a subsidiary of Mitsui & Co. (U.S.A.), Inc., was a terminal and storage facility operator that had been servicing the petrochemical industry for over five decades [1]. ITC was founded on February 24, 1972, with the purpose of constructing, operating, maintaining, and growing terminal assets [2]. ITC currently owns and operates two terminals near Houston, Texas: the ITC Deer Park and ITC Pasadena terminals. ITC also operates one terminal near Baton Rouge, Louisiana (Exxon Anchorage terminal), which is owned by another company [1].[a] Outside of the United States, the company operates one terminal in Antwerp, Belgium: the ITC Antwerp terminal.

1.2 ITC DEER PARK TERMINAL OVERVIEW

The ITC Deer Park terminal is a bulk liquid storage terminal situated on the inlet of Tucker Bayou in the Houston Ship Channel (**Figure 1**) [1] [3]. On December 1, 1971, ITC began construction on the 11-acre parcel of land located on the inlet of Tucker Bayou that would become the ITC Deer Park terminal [1]. ITC acquired additional acreage and infrastructure between 1974 and 2013, which led to the expansion of the ITC Deer Park terminal's size, capability, and capacity [1]. At present, the ITC Deer Park terminal is a 265-acre facility equipped with 227 storage tanks, both rail car and tank truck access, six tanker berths, 10 barge docks, and multiple pipeline connections [3] [4].

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[a] ITC participates in the American Chemistry Council (ACC) Responsible Care® program as a Responsible Care® Partner in the Terminal Operators Sector. The Responsible Care® Partner Program is open to companies that have direct, substantial involvement in the distribution, transportation, storage, use, treatment, disposal, or sales and marketing of chemicals. Responsible Care® Partners are expected to adhere to the same Responsible Care® requirements as ACC members. Partner companies are separated into different sectors based on their primary business operation. These companies strive to continually improve environmental, health, safety, and security performance for all their chemical operations. The ITC Deer Park terminal is both RC 14001 and ISO 9001 certified.

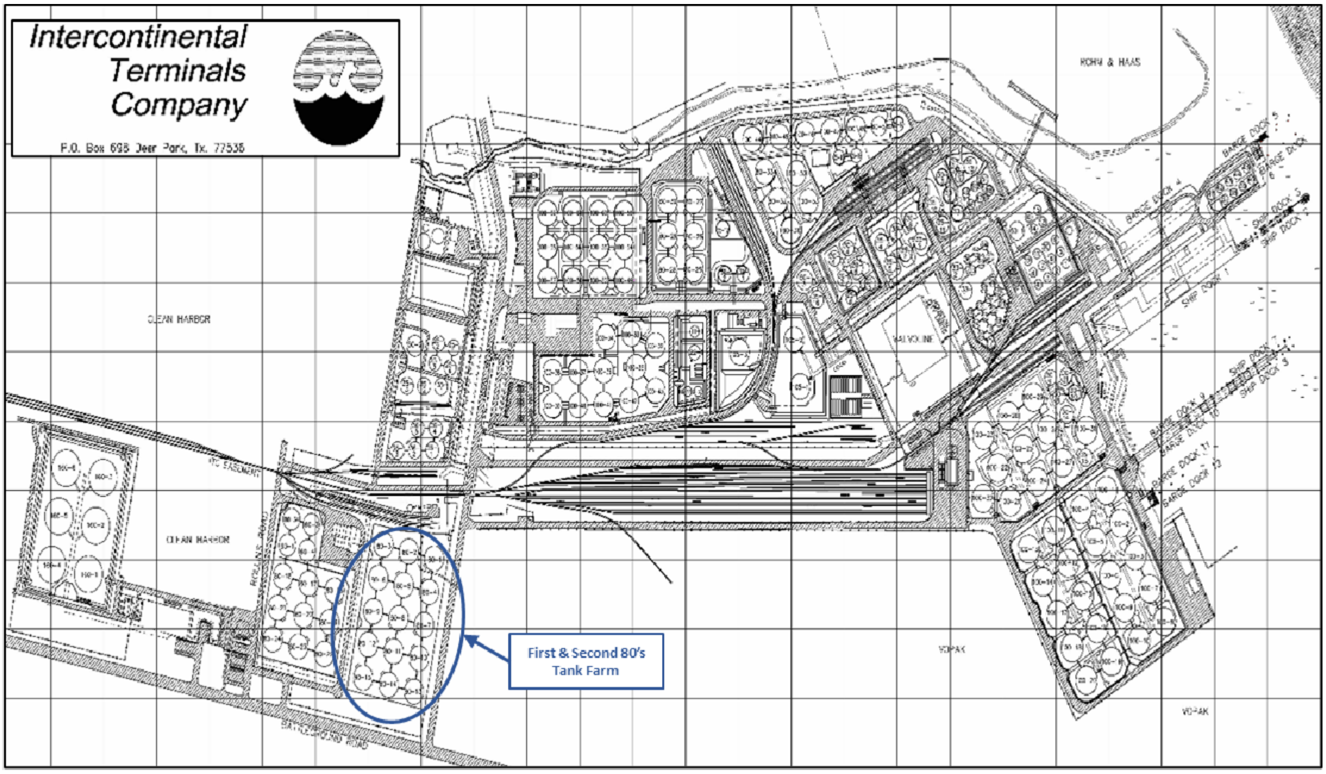

Figure 1. ITC Deer Park terminal overall plot plan. (Credit: ITC, annotations by CSB)

At the time of the incident, the ITC Deer Park terminal housed 242 fixed storage tanks, which ranged in size from 8,000- to 160,000-barrel capacities [3]. The terminal was separated into multiple tank farms, each comprised of multiple tanks within a common secondary containment area.[a] The tanks were used to store petrochemical liquids and gases, fuel oil, bunker oil, and distillates for various oil and chemical companies that leased the tanks from ITC [5]. The overall on-site storage capacity at ITC Deer Park was approximately 13.1 million barrels [3]. According to the company's website, the ITC Deer Park terminal handled approximately 770 ships, 3,700 barges, 12,000 rail tank cars, and 33,600 cargo tank trucks on an annual basis, with a total annual throughput of about 144 million barrels [2]. The terminal was staffed with approximately 270 employees at the time of the incident [1].

Records and other information provided by ITC indicate that portions of the ITC Deer Park terminal, including storage tanks containing butadiene, isoprene, liquified petroleum gas (LPG), and vinyl acetate monomer, were covered by both the U.S. Occupational Safety and Health Administration (OSHA) Process Safety Management (PSM) standard and the U.S. Environmental Protection Agency (EPA) Risk Management Program (RMP) rule. As will be discussed in Section 4.5, due to the atmospheric storage tank exemption contained in the OSHA PSM standard, the First & Second 80's tank farm was not covered by either regulation at the time of the incident.

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[a] Secondary containment for aboveground storage tanks is defined as capturing the entire contents of the largest tank in the containment area in the event of a leak or spill. Doing so allows sufficient time for cleaning up the product before it moves beyond the secondary containment envelope and poses a more serious safety and environmental contamination hazard. Secondary containment usually consists of some combination of dikes, liners, ponds, impoundments, curbs, outer tanks, walls, or other equipment capable of containing the stored liquids. The most common forms are dikes and berms [86].

1.3 SURROUNDING AREA

Figure 2 shows the ITC Deer Park terminal and depicts the areas within roughly one, three, and five miles of the terminal. The area surrounding the ITC Deer Park terminal is mainly industrial, and no persons reside within a one-mile radius of the terminal. Nearby structures are primarily industrial facilities. Summarized demographic data for the area within a roughly three-mile radius of the ITC Deer Park terminal are shown below in **Table 1**. More detailed demographic information can be found in Appendix B.

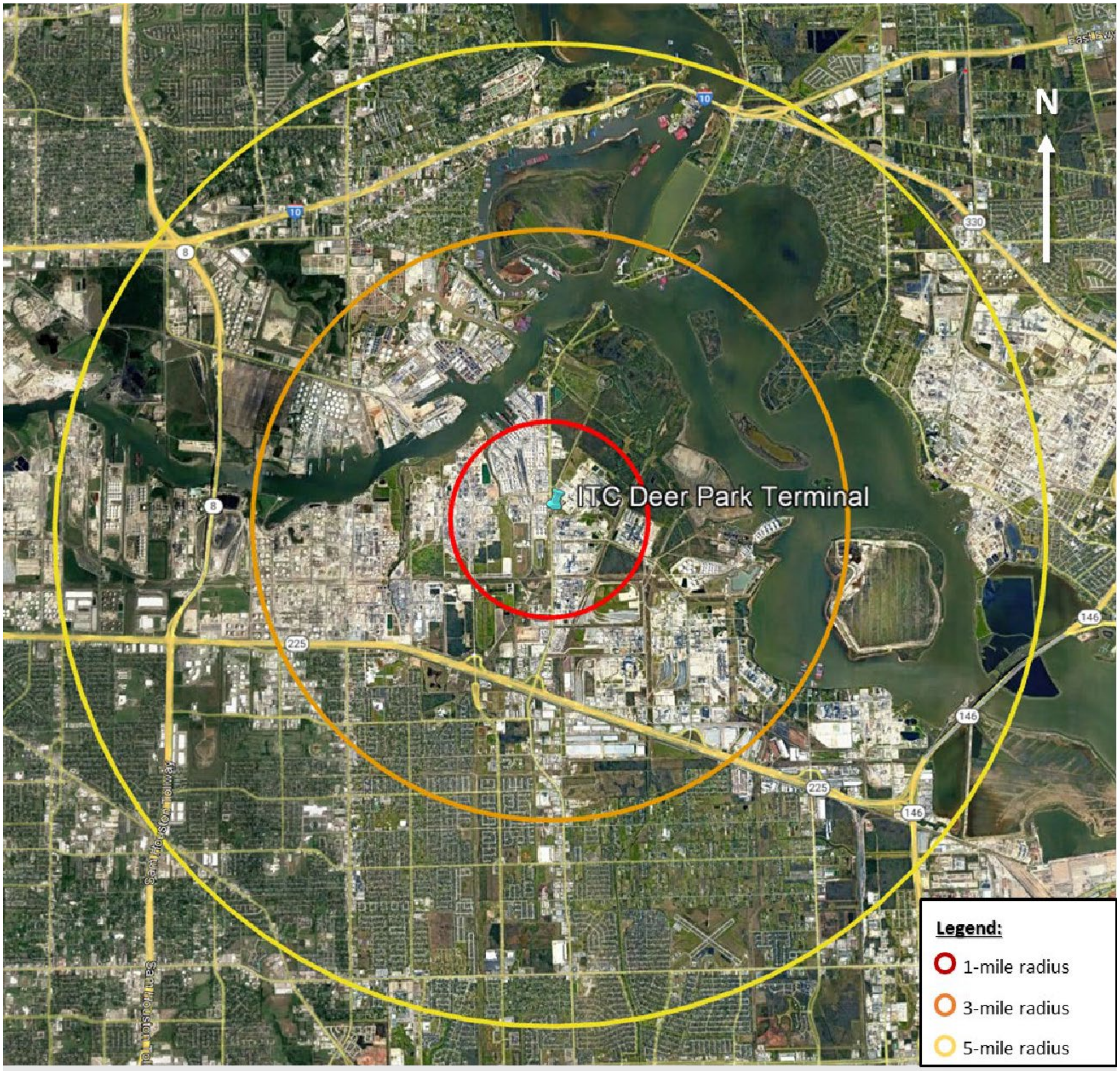

Figure 2. Overhead satellite image of ITC Deer Park terminal and the surrounding area. (Credit: Google Earth, annotations by CSB)

Table 1. Summarized demographic data of approximately 3-mile radius of ITC Deer Park terminal. (Credit: CSB)[a]

Population	Race & Ethnicity		Per Capita Income	Persons Below Poverty Line	Number of Housing Units	Types of Housing Units	
27,934	White	59%	$ 45,593	8%	9,921	Single Unit	88%
	Black	1%				Multi-Unit	8%
	Native	0%				Mobile Home	3%
	Asian	1%				Boat, RV, Van, etc	0%
	Islander	0%					
	Other	0%					
	Two+	2%					
	Hispanic	36%					

1.4 FIRST & SECOND 80'S TANK FARM

The incident occurred in what was commonly referred to as the First & Second 80's tank farm at the ITC Deer Park terminal (**Figure 3**). The First & Second 80's tank farm consisted of fifteen (15) 80,000-barrel (3,360,000-gallon) capacity aboveground atmospheric storage tanks situated within a common containment area that measured approximately 732 feet in length by 449 feet in width. The storage tanks measured 110 feet in diameter and 48 feet in height and were arranged in a 3 x 5 grid pattern, oriented in the east-west direction lengthwise. The aboveground atmospheric storage tank involved in the initial fire, Tank 80-8, was positioned in the center of the First & Second 80's tank farm (**Figure 4**).

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[a] The Census Bureau reports that the overall per capita income for the United States from 2017-2021 was $37,638 [87].

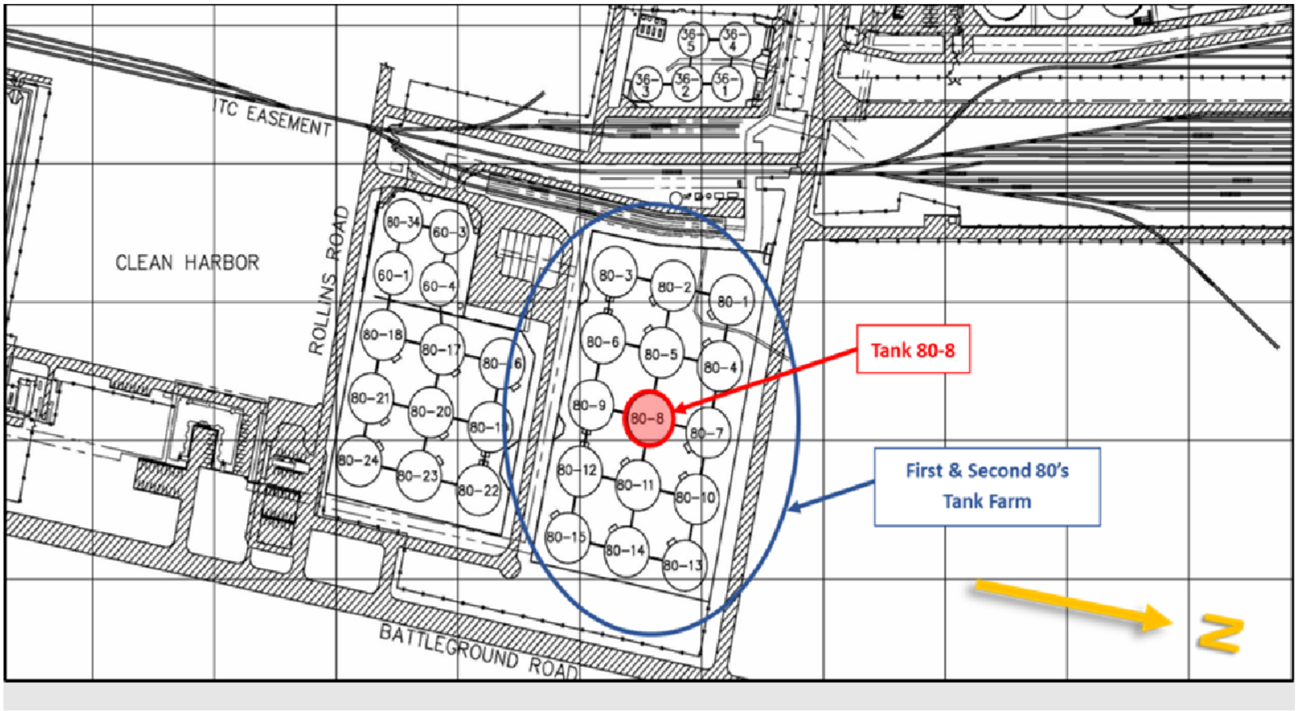

Figure 3. Plot plan of tank farm. Excerpt from overall plot plan for the ITC Deer Park terminal showing the location of the First & Second 80's Tank Farm. (Credit: ITC, annotations by CSB)

Figure 4. Tank 80-8, shown in 2007. (Credit: ITC)

The First & Second 80's tank farm was constructed in two phases, the first of which included Tanks 80-1 through 80-12. On June 17, 1976, the Texas Air Control Board (TACB) authorized the construction of twelve (12) 80,000-barrel cylindrical storage tanks at the ITC Deer Park terminal.[a] On September 1, 1977, the TACB authorized the construction of an additional twelve (12) 80,000-barrel cylindrical storage tanks, including Tanks 80-13 through 80-15. The TACB issued an operating permit for Tanks 80-1 through 80-12 in 1978, and another for Tanks 80-13 through 80-24 several years later. The original operating permits included a list of approved products for storage, including gasoline, benzene, cyclohexane, sodium sulfide solution, and fuel oil. Over the years, ITC requested amendments to these permits for storage of other products including ethylene dichloride, ethanol, isopropyl alcohol, and toluene. The operating permits were also periodically amended by the TACB's successor agency, the Texas Commission on Environmental Quality (TCEQ) [6]. The terminal currently operates pursuant to TCEQ Air Quality Permit No. 1078 and Federal Operating Permit No. O1061. At the time of the incident, Tanks 80-1 through 80-15 contained various hydrocarbon and petrochemical products, including naphtha, xylene, toluene, pyrolysis gasoline (Pygas), base oil, and gasoline blendstock.

1.5 TANK 80-8 BUTANE INJECTION SYSTEM DESCRIPTION

According to the original operating permit issued for Tank 80-8 on February 14, 1978, the atmospheric storage tank was initially approved for the loading and storage of gasoline, benzene, or cyclohexane; all of which are flammable liquid hydrocarbon compounds or mixtures.[b] ITC indicated that, since that time, Tank 80-8 had been used to load and store various liquid hydrocarbon products in accordance with the terms of the applicable versions of its Title V Federal Operating Permit and TCEQ Air Quality Permit.[c] Most recently, Tank 80-8 was under lease by a local company for loading and storage of naphtha. Pursuant to TCEQ Air Quality Permit No. 1078, ITC was authorized to store naphtha in internal floating roof tanks, which included Tank 80-8.

In 2014, Tank 80-8's lessee requested the addition of butane injection capability to the tank to boost the octane level of product stored in the tank, a practice commonly used by midstream companies to prepare the product for use as a gasoline blendstock [7, p. 1]. Butane is a colorless, liquified petroleum gas that is typically less expensive than naphtha [7, p. 1]. Blending butane with naphtha increases the overall naphtha product volume. However, since butane has a higher vapor pressure than naphtha, only a limited amount may be added to ensure that the final butane-enriched naphtha product remains within established Reid Vapor Pressure (RVP)[d] or True Vapor Pressure (TVP)[e] limits. ITC evaluated the tank lessee's request and designed the Tank 80-8 Truck Butane Injection System based on what ITC referred to as the "best known process for butanizing."

The Tank 80-8 Truck Butane Injection System originated at the 80's truck rack, located southwest of the tank farm (**Figure 5**), and terminated at an injection point in Tank 80-8's circulation line (**Figure 6**). The system was

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[a] The tanks measured 110 feet in diameter and 48 feet in height, and were fabricated by the Southwest Tank & Treater Manufacturing Company, Henderson, Texas, in accordance with API Standard 650, *Welded Tanks for Oil Storage* (API STD 650), between 1976 and 1977.

[b] Hydrocarbons are organic chemical compounds composed only of carbon (C) and hydrogen (H) atoms. Hydrocarbons are the principal constituents of petroleum and natural gas [80].

[c] In 1992, ITC consolidated the individual TACB permits into one TCEQ air quality permit (No. 1078) that covers all of the permitted tanks at the ITC Deer Park terminal. ITC operated Tank 80-8 in accordance with the terms of the permit.

[d] RVP is the absolute vapor pressure of volatile crude oil and volatile nonviscous petroleum liquids, except liquified petroleum gases, as determined by ASTM D323-82 or 94. 40 C.F.R. § 60.111(l).

[e] TVP is the equilibrium partial pressure exerted by a petroleum liquid as determined in accordance with methods described in API Bulletin 2517, *Evaporation Loss from External Floating-Roof Tanks*, Second Edition, February 1980. 40 C.F.R. § 60.111(i).

designed so that the butane unloading operation could not begin unless the Tank 80-8 circulation pump was turned on, to ensure that butane-enriched naphtha product was circulating in the line. Once this condition was met, an ITC operator positioned at the 80's truck rack could then open the butane injection control valve to commence butane unloading operations. Nitrogen was used to unload the butane from the truck, and through two-inch piping to the Tank 80-8 circulation line, at which point the butane combined with the existing butane-enriched naphtha product in the tank. The Tank 80-8 circulation pump remained on throughout the unloading activity, and for several hours afterward, in order to facilitate the mixing of the naphtha and butane.

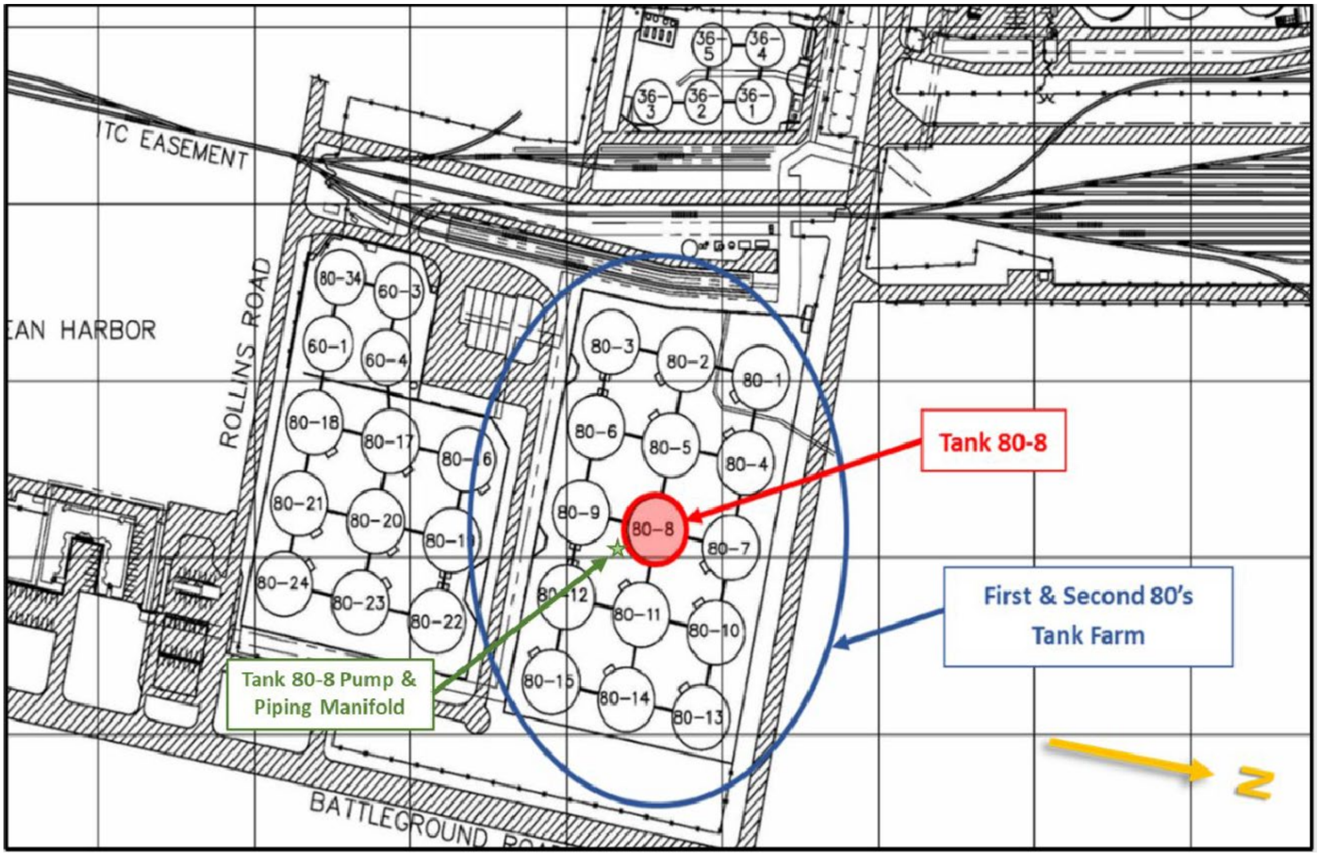

Figure 5. Plot plan of 80's truck rack. Excerpt from overall plot plan for the ITC Deer Park terminal showing the location of the 80's truck rack and First & Second 80's tank farm. (Credit: ITC, annotations by CSB).

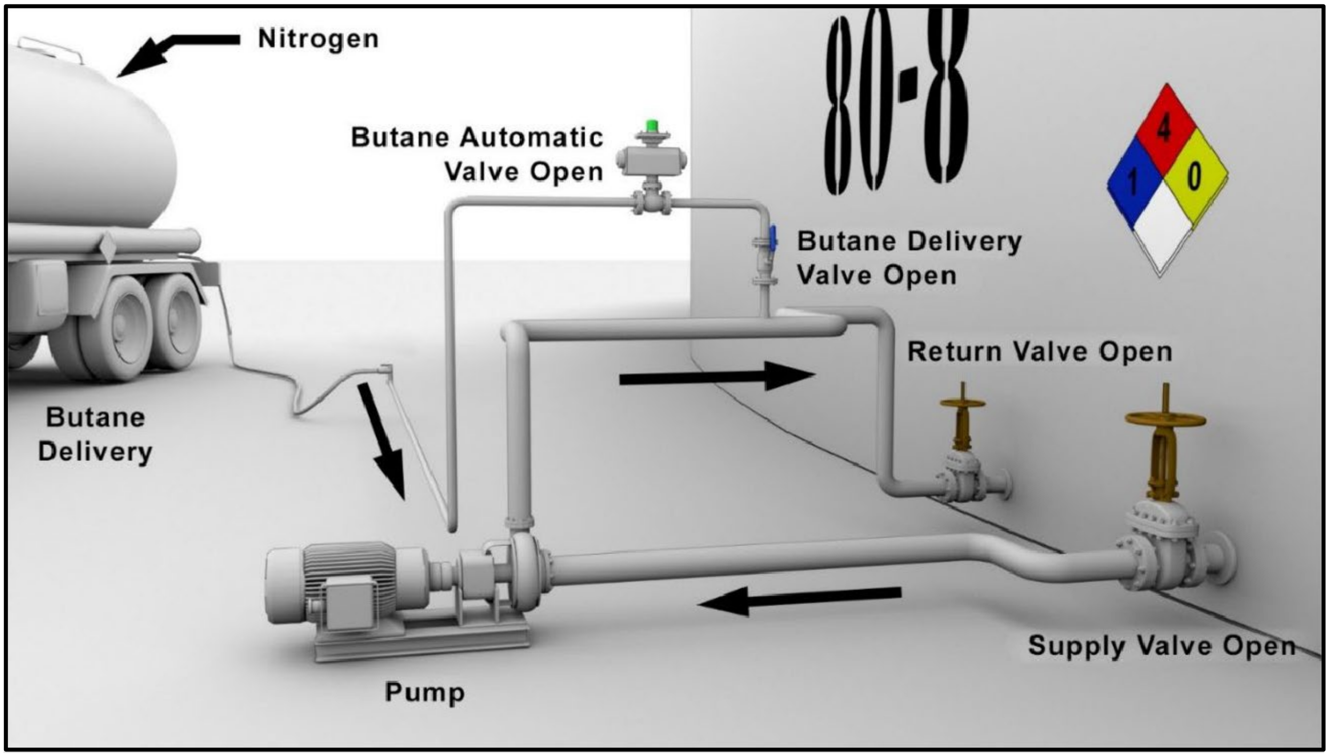

Figure 6. Simplified schematic showing ITC's butane injection system prior to 2016. The arrows in the figure show the butane flow direction and the naphtha product circulation path through the piping. Note: schematic not to scale. (Credit: CSB)

Although the OSHA PSM standard and EPA RMP rule did not apply to Tank 80-8, ITC used its management of change (MOC) process to document the Tank 80-8 Truck Butane Injection System project.[a] As part of this MOC, ITC completed a pre-startup safety review (PSSR) for the project on August 18, 2014. About a year and a half later, in January 2016, the company revised the Tank 80-8 Truck Butane Injection System to replace the majority of two-inch piping with four-inch piping in an effort to reduce the amount of time required to unload butane from the cargo tank trucks.[b]

1.6 NAPHTHA AND BUTANE CHARACTERISTICS

According to the Safety Data Sheet (SDS)[c] provided by Midcoast Energy, LLC (Tank 80-8 lessee), naphtha is a colorless to light yellow, flammable liquid with a characteristic hydrocarbon-like odor. It is a complex mixture of petroleum hydrocarbons in the C4-C10 range, and one of the more volatile forms of petroleum [8]. Naphtha is typically used as a feedstock for producing ethylene and propylene, or a gasoline blending component. It has a flash point of -7.1°F and lower explosive limit (LEL) of 1.2%. Naphtha has a higher vapor density than air; thus,

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[a] Although parts of the Deer Park terminal were not covered under OSHA's PSM standard, ITC applied some elements of PSM, including MOC, to the entire terminal.

[b] Note: The figures show the Tank 80-8 piping manifold before the January 2016 revision, when ITC replaced the majority of the two-inch piping with four-inch piping.

[c] *Midcoast Energy, LLC* provided ITC the SDS for the naphtha stored in Tank 80-8. The components and characteristics of the naphtha product may vary within anticipated ranges between shipments.

if released from containment and exposed to atmospheric conditions, its flammable vapors typically collect along the ground or in low-lying areas.[a] In its liquid form, naphtha is lighter than water and has only negligible water solubility; thus, it will float on water.[b,c] The SDS indicates that "suitable extinguishing media" for fires involving naphtha include water spray, alcohol-resistant foam, dry chemical, or carbon dioxide; a solid water stream should not be used, as it may scatter and spread the fire. In the case of large fires involving naphtha, the SDS indicates that water spray, fog, or firefighting foam should be utilized to fight the fire, while water spray should be used to cool fire-exposed containers. Naphtha is a Class I liquid—a liquid with a flash point below 100°F—per National Fire Protection Association (NFPA) classifications [9, p. 12].

Butane is a Category 1 flammable gas (per 29 CFR §1910.1200) and is a substance covered by the EPA RMP rule at quantities exceeding 10,000 pounds.[d] Butane is highly flammable and can be easily ignited by heat, sparks, or flames [10].

2 INCIDENT DESCRIPTION

The sections below detail the incident sequence. Appendix C contains a summarized timeline of events.

2.1 TANK 80-8 BUTANE DELIVERIES

On the evening of March 16, 2019, two butane truck deliveries were scheduled for Tank 80-8. At approximately 6:45 p.m., the area operator who was assigned to the First & Second 80's tank farm (Operator 1) received a call from the operator stationed at the truck loading rack (Operator 2) requesting that he get Tank 80-8 ready for the first butane delivery. Operator 1 arrived at the Tank 80-8 piping manifold shortly thereafter and took a level gauge reading on the tank to confirm that there was enough room in the tank to accommodate the planned butane deliveries. At 6:54 p.m., Operator 1 started the Tank 80-8 circulation pump and verified that the circulation valve was fully open. He then manually adjusted the pressure on the circulation line to 40 pounds per square inch (psi) using the chainwheel operated valve. Once the circulation pressure was set, Operator 1 informed Operator 2 that he could start offloading the butane truck. At approximately 7:23 p.m., Operator 2 initiated the unloading process at the truck loading rack. The first scheduled delivery was completed at 8:15 p.m. Approximately 170 barrels of butane were added to Tank 80-8.

Later that evening, Operator 1 received a call for the second butane truck delivery. He proceeded to the Tank 80-8 piping manifold and confirmed that there was room in the tank, the pump was still turned on, and that the valves were still properly aligned. At approximately 9:30 p.m., he notified Operator 2 that he could begin unloading the second truck. Operator 2 started unloading the butane truck shortly thereafter, and the second scheduled delivery of roughly 193 barrels of butane was completed at approximately 10:29 p.m. that evening. Following completion of the two butane truck deliveries, the Tank 80-8 circulation pump remained on overnight to circulate the roughly 70,300 barrels of butane-enriched naphtha product contained in the tank. Operator 1 told

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[a] The SDS indicates that naphtha has a vapor density of 3.5, compared with that of air, which is 1.0.

[b] The SDS indicates that naphtha has a specific gravity of 0.77, compared with that of water, which is 1.0.

[c] According to the Certificate of Analysis (COA) for a sample taken from Tank 80-8 on March 12, 2019, the specific gravity of the butane-enriched naphtha product in Tank 80-8 was around 0.68, as opposed to the 0.77 referenced on the SDS.

[d] The EPA's List of Regulated Substances (per 40 CFR § 68.130 – Tables 3 and 4 with a threshold quantity of 10,000 pounds).

investigators that during the butane deliveries, the Tank 80-8 circulation pump appeared to be operating normally.

A chemical tanker, *Stena Performance,* was scheduled to arrive at 12:00 p.m. on March 17, 2019. The entire contents of Tank 80-8 were intended to be transferred to the ship at that time.

2.2 INITIAL BUTANE-ENRICHED NAPHTHA PRODUCT RELEASE

On the morning of March 17, 2019, as the Tank 80-8 circulation pump continued to operate, distributed control system (DCS) data for the tank indicated a series of unanticipated changes in the monitored operating pressures, flow rate, and tank volume. Beginning at approximately 7:25 a.m., the pump discharge pressure began to increase with no change in operation having occurred (**Figure 7**). By 8:45 a.m., the pump discharge pressure had gradually increased from 80 psi to 84 psi. At approximately 9:30 a.m., when the mechanical seal on the pump failed and butane-enriched naphtha product began to release to the atmosphere, the recorded tank level began to decrease, and recorded average flow rate[a] for the tank, automatically calculated from changes in tank level measurements, began to increase (**Figure 8**). At approximately 9:35 a.m., the pump discharge pressure abruptly dropped to 80 psi, and within the next 10 minutes dropped further to 75 psi. At the same time, the recorded average flow rate of material from the tank had increased to about 158 barrels per hour (bph), and by 9:44 a.m. had increased to over 388 bph.

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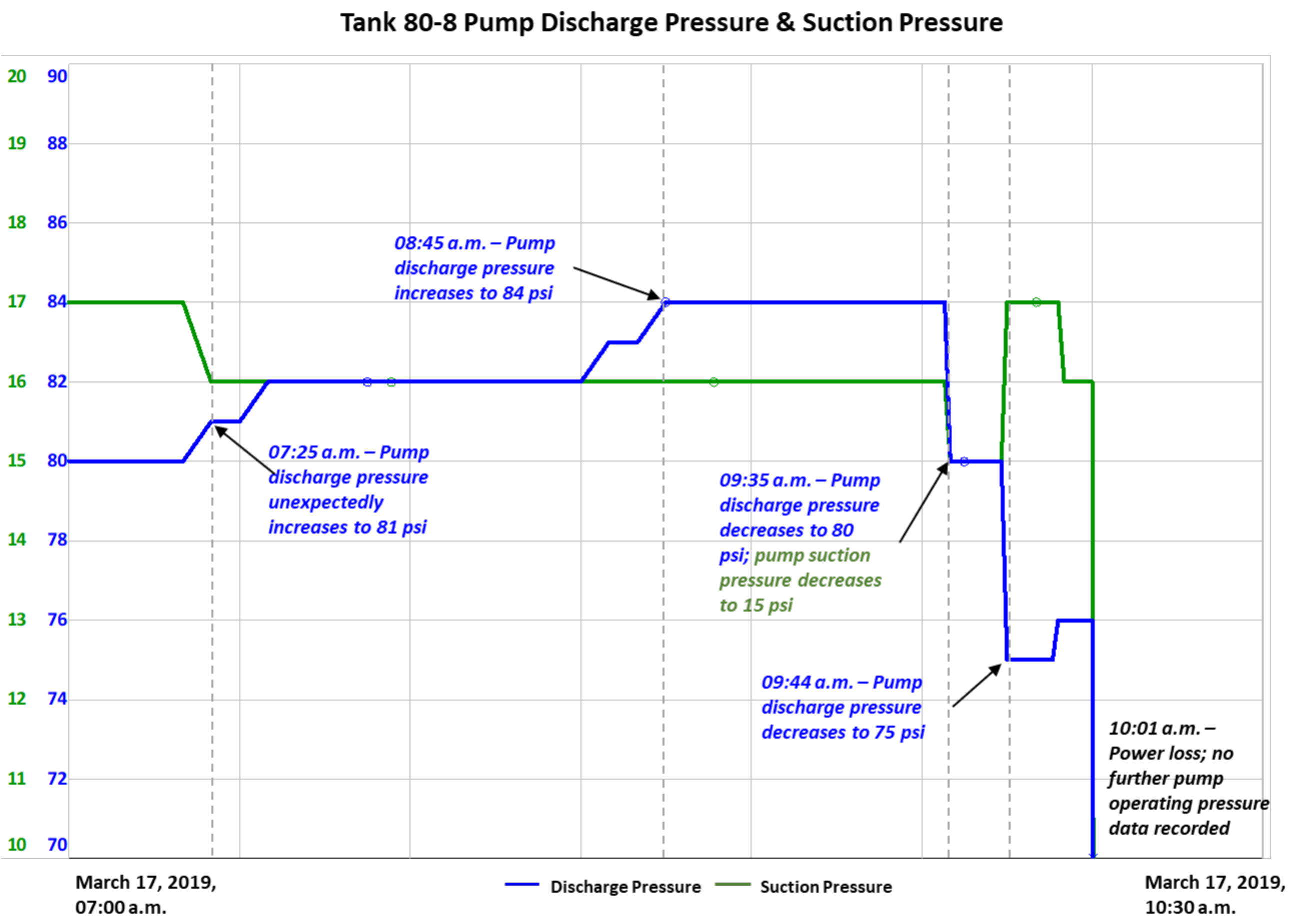
[a] The flow rate, or "BPH Rate," is calculated in barrels per hour (bph). Logic configured in the SCADA system calculates the flow rate for each tank. The rate is based on the difference in the gross tank volume in a time span of 60 seconds. This difference in volume is fed into a moving average calculation function block containing 15 samples of the gross volume difference value. Every 60 seconds a new difference value is fed into the moving average calculation, replacing the oldest value, and a new average is derived. This calculation is only activated if the tank is in **Inbound or Outbound mode**; otherwise, the rate will be zero if the tank is in **Idle mode**.



Tank 80-8 Pump Discharge Pressure & Suction Pressure

08:45 a.m. – Pump discharge pressure increases to 84 psi

07:25 a.m. – Pump discharge pressure unexpectedly increases to 81 psi

09:35 a.m. – Pump discharge pressure decreases to 80 psi; pump suction pressure decreases to 15 psi

09:44 a.m. – Pump discharge pressure decreases to 75 psi

10:01 a.m. – Power loss; no further pump operating pressure data recorded

Figure 7. Recorded data historian trends showing recorded pump operating pressure data for Tank 80-8. (Credit: CSB)

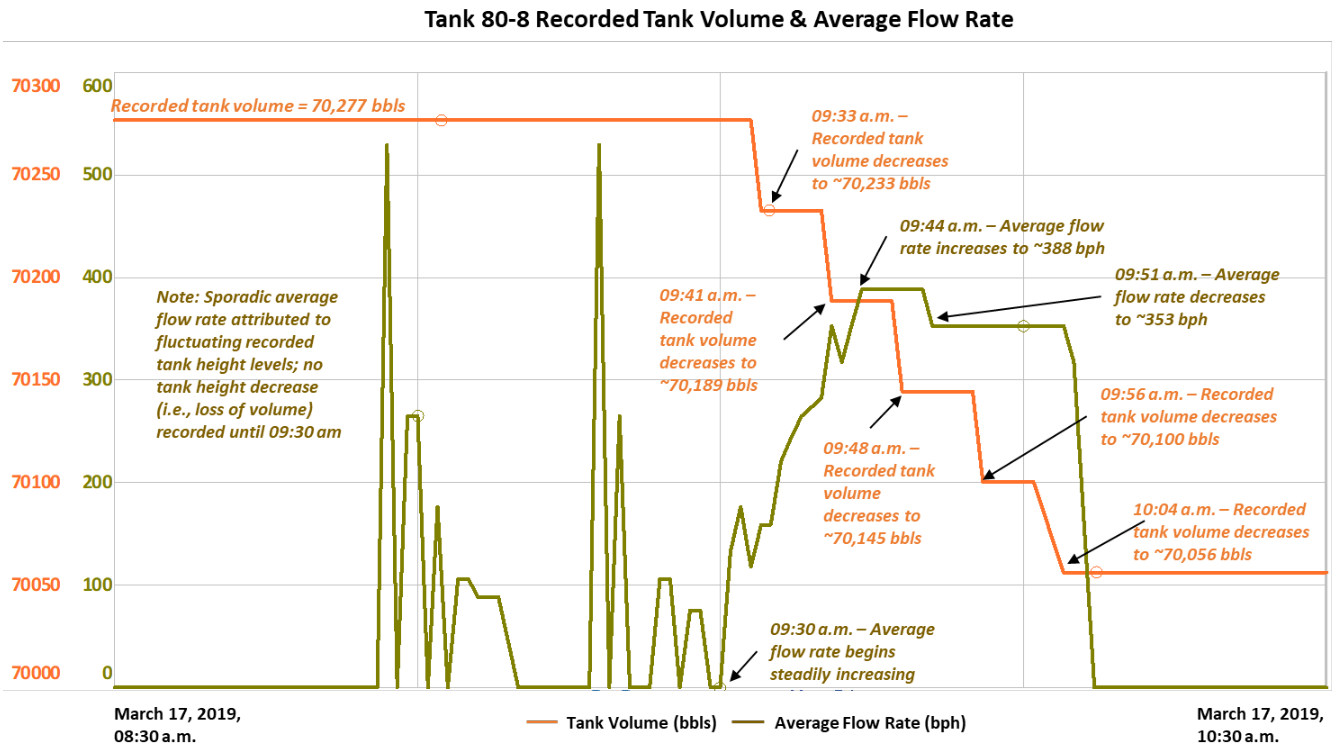


Figure 8. Recorded data historian trends showing recorded average flow rate and tank volume data for Tank 80-8. (Credit: CSB)

Between 9:30 and 10:00 a.m., the recorded tank volume[a] in Tank 80-8 decreased by more than 177 barrels as the naphtha product continued to release from the failed pump.[b] At 10:00:46 a.m., approximately 30 minutes after the release began, the butane-enriched naphtha product releasing from the Tank 80-8 piping manifold ignited (**Figure 9**). No operators were working outside in the First & Second 80's tank farm during this time frame. The acting shift manager was working in the adjacent Third 80's tank farm that morning and an operator was working in the nearby 100's tank farm. However, neither of them heard, saw, or smelled anything out of the ordinary during the time of the release. The First & Second 80's tank farm was not equipped with a gas detection system.

The unanticipated changes in the computer control system data did not trigger any alarms in the central control room (CCR) since the changes did not reach any applicable alarm setpoints.[c] The Hi and Lo alarm setpoints for the Tank 80-8 pump discharge pressure were 130 and 0 psi, respectively. The CCR operator on duty was not

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[a] The tank volume, or "Gross BBLS," is calculated using the ITC tank strapping tables, which correlate a level in inches to a corresponding volume within a specific tank. Calibration is performed by third-party vendors for product management purposes. This volume is calculated as gross barrels (42 U.S. gallons) with no correction factors applied. The strapping table is converted into a data table format compatible with the SCADA system. The converted table is placed into the control system logic function block for each specific tank. The SCADA system polls the tank gauging system, which for Tank 80-8 was a Saab Radar Gauge, to receive a product level in 16ths of an inch. This value is multiplied by 16 to derive inches of level. This level value is fed into the logic function block to derive the tank gross volume based on the level reading from the tank gauge. If the level value is between two table entries, the logic function block interpolates the volume.

[b] The DCS records "Gross BBLS" changes in increments of 40 barrels; thus, the actual amount of product lost from Tank 80-8 at this time was likely more than 206 barrels, as opposed to the 177 barrels indicated on the recorded data.

c The Hi and Lo alarm setpoints for the Tank 80-8 pump discharge pressure were 130 and 0 psi, respectively.

actively monitoring Tank 80-8 because no loading or unloading activity was ongoing at the time. As a result, the CCR operator did not identify the ongoing reduction in tank volume and took no measures to secure the butane-enriched naphtha product release.

At 10:01 a.m., control system event logs indicated an uncommanded stop for the Tank 80-8 circulation pump. Subsequently, the Tank 80-8 circulation pump lost communication with the DCS as the sensors responsible for taking tank height readings lost connectivity with the system, likely as a result of power loss from the fire. No further control system data for Tank 80-8 or the pump were available after this time. That afternoon, at 12:09 p.m., DCS data stopped recording for all tanks located in the First & Second 80's tank farm as a result of power loss from the fire.

Figure 9. ITC Deer Park terminal security camera footage showing fireball over First & Second 80's Tank Farm at 10:00:46 a.m. on March 17, 2019. (Credit: ITC, annotations by CSB)

2.3 INCIDENT RESPONSE AND FIRE PROGRESSION

When the fire erupted shortly after 10:00 a.m.[a] on March 17, 2019, the acting shift manager was finishing up work in the adjacent tank farm, about 600 feet away from Tank 80-8. He was walking north, between Tanks 80-17 and 80-20 (**Figure 3**), toward his truck when he heard an unexpected noise that he described as sounding like two railcars coupling. A few seconds later he looked up and saw fire between Tanks 80-8 and 80-11.

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[a] 10:00:46 a.m. from ITC surveillance camera footage.

The acting shift manager hopped over the containment wall to exit the tank farm and immediately reported the fire via his handheld radio and instructed members of ITC's Emergency Response Team (ERT)[a] to respond to the First & Second 80's tank farm. He then called the facility's Security Office and instructed security personnel to activate the plant-wide alarm to alert all on-site personnel of the incident. Between approximately 10:03 a.m. and 10:10 a.m., the security officer sounded the fire alarm, made an announcement over the all-call system, and sent out a notification over the computer system, followed by an e-notify message. The acting shift manager continued to make notifications, including a call to the Vice President of Safety, Health, Environmental, Security, Regulatory Compliance, and Operations (VP of Safety) to inform him of the tank farm fire.

Members of the ERT reported to the fire house and prepared to fight the fire. The onsite fire truck arrived at the First & Second 80's tank farm within minutes. The first responding member of the ERT entered the tank farm near Tank 80-12 and attempted to activate the fixed fire monitor[b] located in the center of Tanks 80-8, 80-9, 80-11, and 80-12. However, the fire monitor was engulfed in flames, and he was unable to access or activate it (**Figure 10**). He then approached the fixed fire monitor between Tanks 80-7, 80-8, 80-10, and 80-11, directed it towards the fire at the Tank 80-8 piping manifold, and opened the valve to start the flow of water. The acting shift manager described the flow of water coming out of this monitor as a "trickle" not capable of reaching the fire. Later, another operator in the area activated a fixed fire monitor located on the tank farm containment wall near Tank 80-9. However, the positions of these fixed fire monitors did not allow for them to be aimed directly at the fire engulfing the Tank 80-8 piping manifold, as they were not designed to reach that area. In the meantime, the fire shifted toward Tank 80-11, causing the insulation surrounding the tank to ignite, according to an emergency responder.

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[a] The ERT consisted of a total of 60 ITC employees. During any given shift, roughly 8-10 members of the ERT were typically on duty. All members of the ERT attend the Texas A&M or Calcasieu firefighter training schools annually and participate in quarterly ERT training in-house (i.e., medical, spill, fire, and hazardous materials response).

[b] Fixed fire monitors are fixed master stream devices, manually or remotely controlled, or both, capable of discharging large volumes of water or foam. [NFPA 1964, Standard for Spray Nozzles and Appliances]

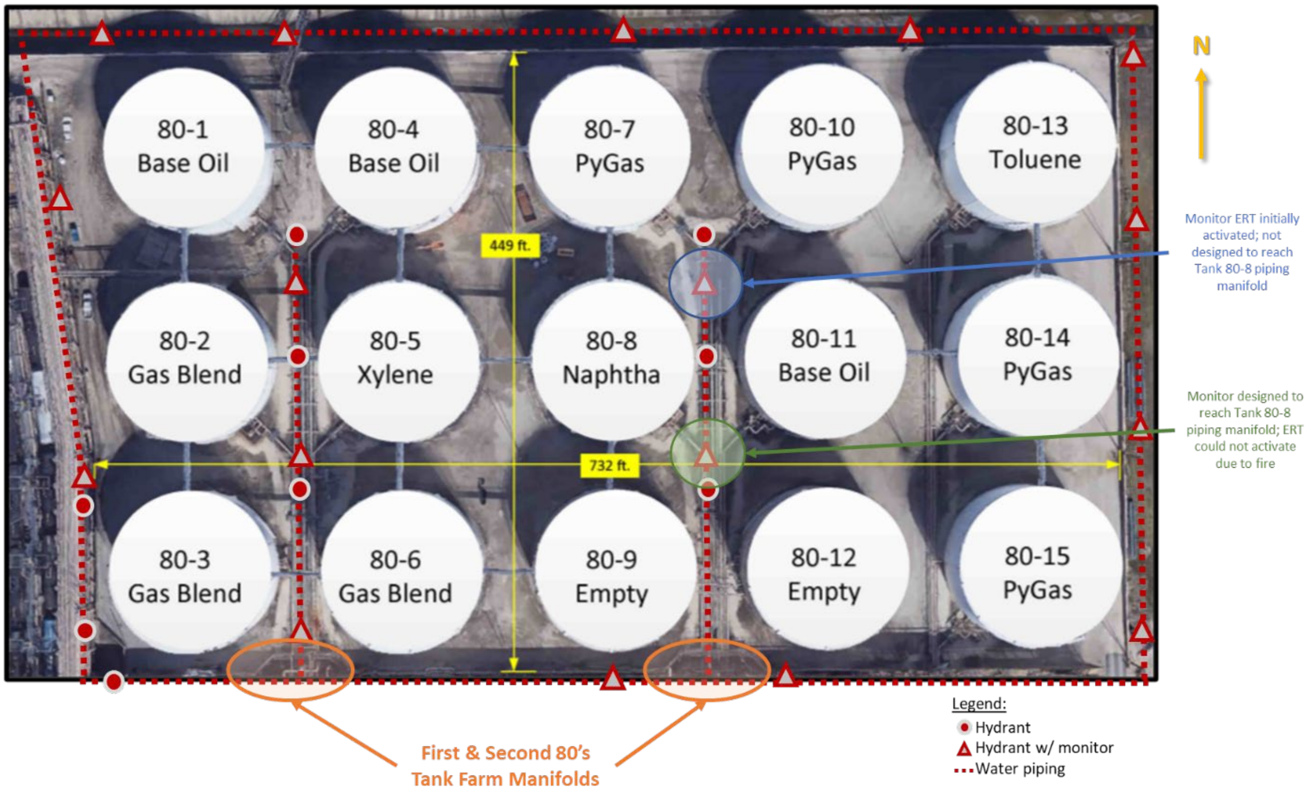

Figure 10. First & Second 80's tank farm layout, including products contained in the tanks at the time of the incident and positions of fire water equipment. (Credit: ITC, annotations by CSB)

While en route to the facility, the VP of Safety, who also led the ERT, was in radio contact with ERT members to ensure that fire pumps were being activated and that on-site personnel were being accounted for by facility management. He also asked the Security Office to notify the Channel Industries Mutual Aid (CIMA) organization of the fire and request that resources be deployed to assist with the response. CIMA is a non-profit group that combines the firefighting, rescue, hazardous materials handling, and emergency response capabilities of the refining and petrochemical industry in the greater Houston metropolitan area [11]. Participating members of the CIMA organization agree to provide emergency response resources and support, including firefighting personnel, equipment, trucks, foam, and supplies to assist with response efforts at other member facilities on a voluntary basis.

When the VP of Safety arrived, his initial observation of the scene was a three-dimensional fire[a] involving the Tank 80-8 piping manifold (**Figure 11**). A liquid pool fire at ground level fully engulfed the Tank 80-8 piping manifold located on the southeast side of the tank, and a pressure fire shot flames horizontally from piping or a flange located roughly six feet above ground level in the same area. Flames from the fire extended up along the side of the tank toward the rim.

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[a] According to a training module from TRANSCAER (Transportation Community Awareness and Emergency Response), an outreach program covering North America: "A three-dimensional fire is defined as a liquid-fuel fire in which the fuel is being discharged from an elevated or pressurized source, creating a pool of fuel on a lower surface. Foam is not effective at controlling three-dimensional flowing fires. It is recommended that firefighters control a three-dimensional flowing fire by first controlling the spill fire; then they may extinguish the flowing fire using a dry chemical agent" [70].

Figure 11. Initial ITC tank fire that ignited at Tank 80-8 on March 17, 2019. (Credit: HCFMO, annotations by CSB)

Given that Tank 80-8 was situated in the center of the First & Second 80's tank farm, the initial response efforts focused on using water to cool the tanks, control the fire, and prevent it from spreading. Since Tanks 80-9 and 80-12 were both empty, resources were not focused on cooling these tanks; however, a wind shift caused the fire to inundate the Second 80's tank farm manifold located in this area, which connected to process piping from other locations in the facility.[a] As a result, the ERT positioned a portable fire monitor between Tanks 80-11 and 80-12 to assist with cooling efforts and prevent the combustible insulation surrounding Tank 80-11 from reigniting. At this time, fire was visible near the rim of Tank 80-8, with flames being expelled through the roof vents (**Figure 12**).

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[a] There were two tank farm manifolds (piping connections) located on the south side of the First & Second 80's tank farm. The tank farm manifolds connected loading piping from other locations in the facility to the piping systems serving individual tanks ("transverse piping"). The piping serving Tanks 80-7 through 80-12 ran north-south between Tanks 80-7 through 80-9 and Tanks 80-10 through 80-12. The piping for Tanks 80-13 through 80-15 ran north-south between Tanks 80-10 through 80-12 and Tanks 80-13 through 80-15.

Figure 12. ITC fire involving Tank 80-8 on the morning of March 17, 2019. (Credit: ABC13 Houston, annotations by CSB)

Additional emergency responders began to arrive at the facility with firefighting equipment and resources, including the Deer Park Fire Department and other members of CIMA, at which time a formal Unified Command was established to oversee the coordinated response. The Unified Command included representatives from ITC, CIMA, the Harris County Fire Marshal's Office (HCFMO), the Harris County Office of Emergency Management, the EPA, the U.S. Coast Guard (USCG), and TCEQ. The response also included support from other federal, state, and local agencies.

Early response efforts focused on life safety[a] and directing water sources at Tank 80-8 and the ground-level fire that engulfed its piping manifold (**Figure 13**). As the fire grew, additional water supply was needed; so, efforts were also underway to establish water supply from neighboring facilities and the Houston Ship Channel via fire boats. Emergency responders continued to work to control the fire; however, it was "growing faster than [they] could do anything."

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[a] Per NFPA, life safety is defined as the protection of human life, including all persons within structure, civilians, and firefighting personnel [71].

Figure 13. The quick attack truck (circled in red) staged between Tanks 80-11 and 80-12 on March 17, 2019. (Credit: Associated Press, annotations by CSB.)

Tank 80-8 was equipped with a fixed foam system that injected foam into the tank to cover the flammable liquid, to suppress the flammable vapors and cut off oxygen supply necessary to support combustion. The fixed foam system on Tank 80-8 was a manually activated system, with supply coming from fire trucks. The hose connection point was located at the Second 80's piping manifold by Tanks 80-9 and 80-12, which was inundated with fire. This made the area inaccessible to responders. Additionally, the tank level was estimated to be about 80% and the tank level indicator was not functioning, so there was no way to confirm the actual tank product height. Without having level indication, there was concern by the VP of Safety and Unified Command that adding foam and water to the tank would potentially cause the tank to overflow and release butane-enriched naphtha product into the containment area. Based on these two significant safety concerns, the Unified Command decided not to activate Tank 80-8's fixed foam system.

Tank 80-8 was not equipped with a remotely operated emergency isolation valve (ROEIV) therefore, the Unified Command discussed trying to manually isolate the main valves on the tank. However, because flames engulfed the entire Tank 80-8 piping manifold, so the area could not be safely accessed, allowing the continued release of butane-enriched naphtha product from Tank 80-8. At approximately 3:00 p.m., the Unified Command sent a team inside the containment area to close the main valves on some of the other tanks in the tank farm. While the team was inside the tank farm, flammable xylene vapors at the roofline of a second storage tank (Tank 80-5) ignited. Concerned for the team's safety, the Unified Command directed the responders to exit the tank farm before they could successfully close any valves. The fire eventually compromised the Tank 80-5 piping manifold, causing xylene to release into the containment area.

Responders continued to fight the fire in defensive mode[a] throughout the evening, applying water and foam to prevent the fire from spreading further.[b,c,d] However, the large amount of water in the tank farm containment area and gaps in the foam blanket allowed the fire to spread. Both naphtha and xylene are lighter than water,[e] therefore, the released flammable products floated on top of the water in the containment area, ignited, and caused several small fires to burn on the water surface where gaps in the foam existed.

The fire continued, and winds continued to shift overnight. By 1:30 a.m. the next morning, Monday, March 18, 2019, five additional storage tanks in the tank farm had caught fire, bringing the total of involved tanks to eight.[f] As responders continued to fight the fires, temporary reductions in water pressure the following afternoon and later that night hindered progress and allowed additional tanks storing flammable substances to catch on fire.[g]

Realizing a need for additional resources to relieve CIMA responders, at approximately 5:00 p.m. that afternoon, ITC reached out to a third-party emergency response services provider, US Fire Pump, located in Holden, Louisiana for assistance in extinguishing the fire. ITC and US Fire Pump signed a formal Emergency Response Agreement by 12:13 a.m. on Tuesday, March 19, 2019. US Fire Pump arrived on scene at approximately 6:48 a.m. with additional response resources including large volume pumps, submersible pumps, large-flow monitors, and truckloads of firefighting foam.

By 1:00 p.m., US Fire Pump resources were fully integrated with local emergency responders already on scene. Firefighters continued response efforts throughout the evening and into the early morning, applying thick blankets of foam and water to suppress the remaining fires.

The fire at the ITC Deer Park terminal was extinguished by approximately 3:00 a.m. on Wednesday, March 20, 2019 (**Figure 14**).[h] Later that evening, at approximately 5:20 p.m., a flare-up occurred at Tank 80-5 (**Figure 15**). Emergency responders were able to contain the fire quickly.

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[a] Defensive firefighting is defined as the mode of manual fire control in which the only fire suppression activities taken are limited to those required to keep a fire from extending from one area to another (NFPA 600 and NFPA 1081).

[b] Emergency responders continued to work on controlling the fire using water and foam to prevent it from spreading, and employed various fire apparatus, including foam engines and foam aerials.

[c] Foam engine, also known as a Foam Pumper – fire apparatus with a permanently mounted fire pump of at least 750 gpm capacity, water tank, and hose body, whose primary purpose is to combat structural and associated fires; in this case, with foam capabilities (adapted from NFPA 1901 and NFPA 1912).

[d] Foam aerial – a piece of fire apparatus with a permanently mounted, power-operated elevating device, including aerial ladders, aerial ladder platforms, telescoping aerial platforms, articulating aerial platforms, and elevating water delivery systems; in this case, with foam capabilities (adapted from NFPA 1002).

[e] Xylene has a specific gravity of 0.87, compared with that of water, which is 1.0.

[f] These five additional tanks included Tanks 80-2, 80-3, 80-6, 80-9, and 80-11, which contained gasoline blendstock and base oil. Flammable vapors ignited along the rooflines of Tanks 80-2, 80-3, 80-6, and 80-9, causing fire to expel from the vents located near the top of the tanks. At this time, the fire involving Tank 80-11 burned at ground level in the area of the piping manifold. Sometime before 5:30 a.m., an additional tank containing toluene, Tank 80-13, became involved in the fire at ground level but was quickly extinguished (Figure 10).

[g] For example, Tanks 80-14 and 80-15, which caught fire in the early hours of March 19, were located in the southeast corner of the tank farm (Figure 10) and contained Pygas, a highly flammable liquid.

[h] Emergency responders continued to spray foam and water on the tanks to keep them cool, prevent vapors from escaping, and prevent any of the remaining material in the containment area from reigniting.

Figure 14. First & Second 80’s tank farm on fire on Tuesday, March 19, 2019, and fully extinguished on Wednesday, March 20, 2019. (Credit: KHOU 11 News)

Figure 15. Tank 80-5 flare-up that occurred on March 20, 2019. (Credit: "Raw video ITC fire reignites in Deer Park", annotations by CSB)

Beginning on the morning of Thursday, March 21, 2019, ITC commenced efforts to move product out of the compromised tanks.[a] On June 19, 2019, the EPA Federal On-Scene Coordinator transitioned the incident from the emergency response phase to the long-term remediation phase. By July 29, 2019, the deconstruction and cleaning of all 15 tanks were complete.

2.4 CONTAINMENT WALL FAILURE AND REMEDIATION

On Friday, March 22, 2019, at around 12:15 p.m., the secondary containment wall surrounding the First & Second 80's tank farm partially collapsed near Tank 80-7. The containment wall displaced laterally due to excessive lateral soil and hydrostatic pressures.[b] The containment wall failure allowed the mixture of released hydrocarbon products, firefighting foam, and contaminated water previously confined to the tank farm to exit the containment area and enter the ditch running adjacent to Tidal Road on the north side of the tank farm

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[a] At around 3:40 p.m., on Friday, March 22, 2019, three tanks, Tanks 80-2, 80-3, and 80-5, re-ignited on the west side of the tank farm. Emergency responders applied foam and were able to fully extinguish the fire in roughly one hour. The product removal and transfer process continued over the course of the next several weeks, during which time emergency responders continued to apply foam to the tank farm to prevent potential flare-ups by maintaining a sufficient level of foam across the tank farm. No additional flare-ups were reported after this event.

[b] Additional detail related to the containment wall failure can be found in Section 4.4.4.

(**Figure 16**). The release also resulted in the potential for elevated levels of volatile organic compounds (VOCs)[a] in the immediate industrial area. As a result, ITC notified its industrial neighbors and local state parks of the potential exposure and recommended that they shelter in place. The breach in the containment wall measured roughly 10 feet in width (**Figure 17**).

Figure 16. Overhead view of the First & Second 80's tank farm containment wall failure that allowed materials to enter the surrounding waterways on Friday, March 22, 2019. (Credit: ITC, annotations by CSB)

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[a] VOCs are compounds that have a high vapor pressure and low water solubility. VOCs are emitted as gases from certain solids or liquids. VOCs include a variety of chemicals, some of which may have short- and long-term adverse health effects [81].

Figure 17. Close-up view of the First & Second 80's tank farm containment wall breach that occurred on Friday, March 22, 2019. (Credit: HCFMO).

The released contaminants eventually entered the Houston Ship Channel via Tucker Bayou. As a result of the breach and subsequent release of materials, the USCG closed a seven-mile stretch of the Houston Ship Channel adjacent to the ITC Deer Park terminal extending from Tucker Bayou and the San Jacinto Monument to Crystal Bay (**Figure 18**) [13]. Additionally, Harris County Precinct 2 temporarily closed eight of the county's waterfront parks [14] The City of La Porte closed all its waterfront parks as well.[a] By 4:00 a.m. the next day, the containment area was secured.

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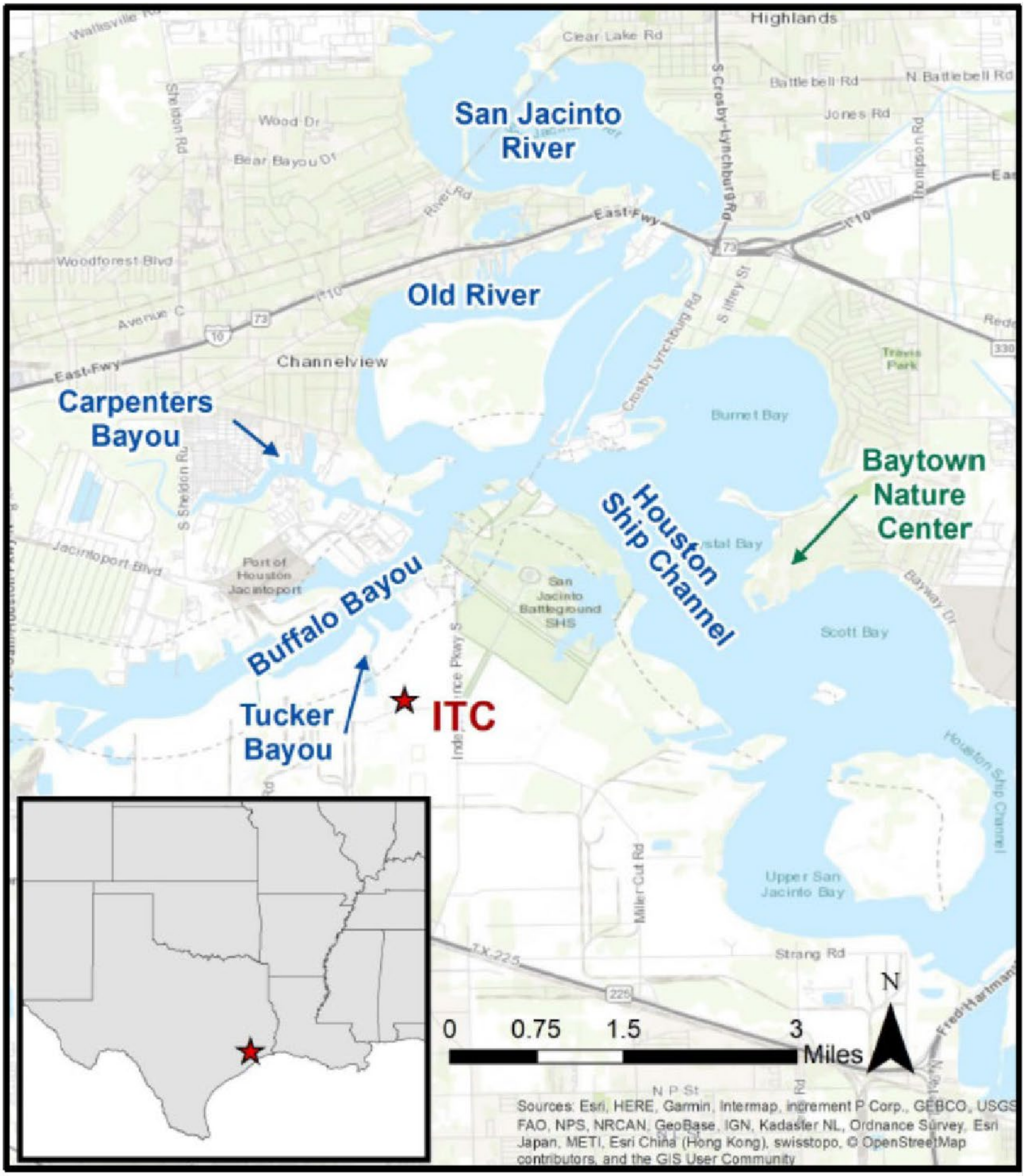
[a] La Porte waterfront parks remained closed until April 16, 2019.



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Figure 18. Houston Ship Channel closure. This map shows the general area where response activities associated with product recovery occurred, with the red star indicating the location of the ITC Deer Park terminal. (Credit: DOI) [15]

On Saturday, March 23, 2019, vacuum trucks and hoses were used to begin recovery of the released hydrocarbon and petrochemical products, foam, and water from the First & Second 80's tank farm and the adjacent drainage ditch. Recovery operations continued until Monday, April 1, 2019, when ITC issued a public statement indicating that the tank farm was stable. ITC stated that crews had recovered 92,222 barrels of hydrocarbon and petrochemical product mixed with foam and water from the area over the past 10 days and that the tank farm contained minimal liquid level covered with foam at this time.

Spill containment and cleanup operations to remove the released products from Tucker Bayou and the Houston Ship Channel also commenced on Saturday, March 23, 2019. Tucker Bayou and the adjacent ITC docks were determined to be the primary impacted locations.[a] Crews deployed boom[b] and response vessels to contain the materials and conduct clean-up operations in these areas, in addition to Patrick Bayou, Old River, Carpenter Bayou, Battleship Texas, Santa Ana Bayou, and the San Jacinto River (**Figure 19**).[c,d] As of Monday, April 1, 2019, ITC reported that crews had deployed more than 130,000 feet of boom and recovered over 61,000 barrels of oily water mix from area waterways to date.

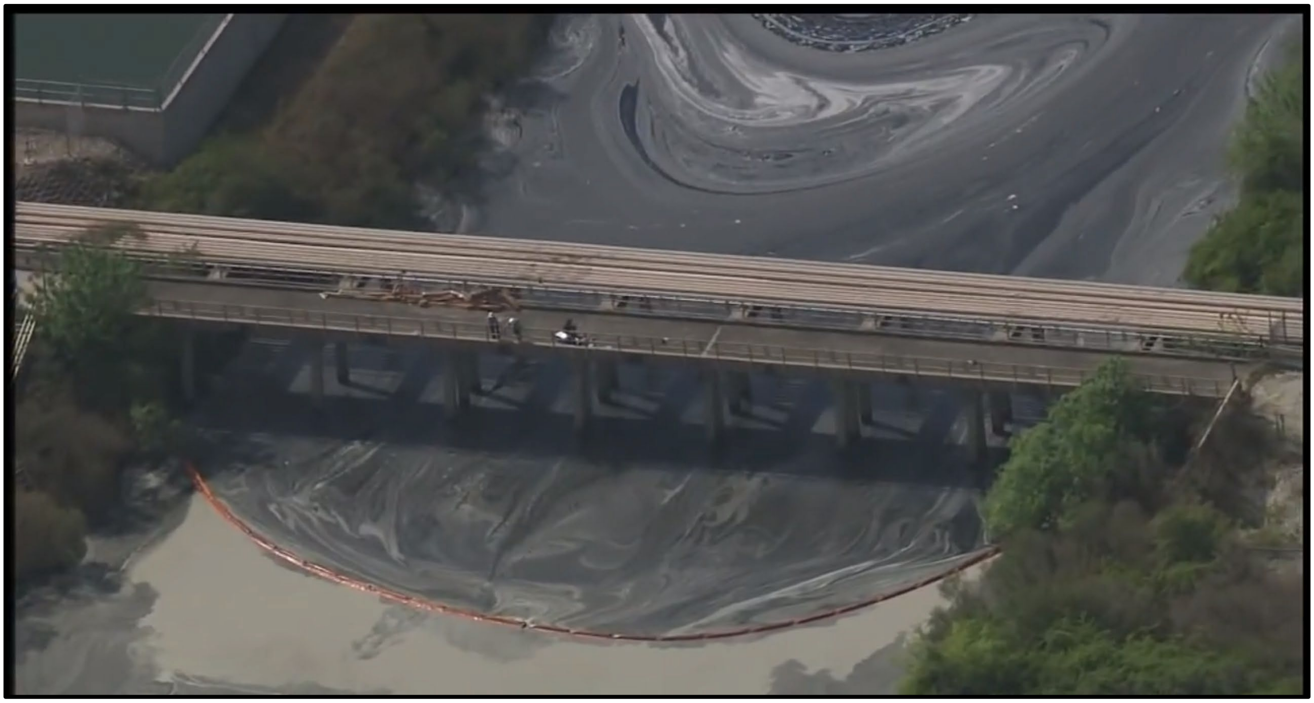


Figure 19. Booming operations conducted in the area of the Houston Ship Channel (Credit: ABC13).

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[a] Shoreline Cleanup and Assessment Techniques (SCAT) surveys to determine the progress of cleanup along segments of affected shoreline were conducted in a joint effort by ITC, USCG, TCEQ, and Texas Parks and Wildlife Department. The SCAT survey team provided recommendations to the Unified Command regarding the need for additional active cleanup, passive cleanup, and/or monitoring.

[b] Boom – floating, physical barriers to oil, made of plastic, metal, or other materials, that slow the spread of oil and keep it contained. Skilled teams deploy boom using mooring systems, such as anchors and land lines [72].

[c] Early in the response a total of 34 vessels, including 15 skimmers, were on scene and actively conducting 24-hour clean-up operations in Tucker Bayou and adjacent areas.

[d] Skimmers – boats and other devices that can remove oil from the sea surface before it reaches sensitive areas along a coastline. In **Figure 19**, oil is being skimmed from the sea surface by a "vessel of opportunity." Sometimes, two boats will tow a collection boom, allowing oil to concentrate within the boom, where it is then picked up by a skimmer [72].

Cleanup operations continued over the course of the next several weeks. A total of 214 response vessels, 142 skimmers, and 50 vacuum trucks, and the placement of nearly 168,000 feet of spill containment boom were utilized during the response. As of May 20, 2019, cleanup operations of all shoreline segments, except for Tucker Bayou (comprising 0.87 miles of shoreline), were complete. Unified Command partners agreed on June 19, 2019, that Tucker Bayou would be transitioned and addressed under a long-term remediation phase and not as part of the emergency response phase [16].

2.5 INCIDENT CONSEQUENCES AND COMMUNITY IMPACT

The ITC Deer Park incident had a direct impact on the surrounding community, including multiple shelter-in-place orders and closures due to benzene-related air quality concerns (**Figure 20**) [17]. Beginning on the morning of Sunday, March 17, 2019, the City of Deer Park issued a precautionary shelter-in-place order for a portion of the community and neighboring industrial facilities.[a] That shelter-in-place order was later expanded to include the entire City of Deer Park, at which time a portion of State Highway 225 was also closed to all traffic. Working under a Unified Command with the EPA, TCEQ, Harris County, USCG, and other agencies, ITC was directed to conduct air monitoring.[b] TCEQ, the EPA, and Harris County staff also deployed air monitoring resources beginning on March 17, 2019. The shelter-in-place order was lifted early the next morning after ITC publicly released an environmental report issued by CTEH that showed all air quality detections recorded were below levels that would represent a public health concern. The City of Deer Park also reopened State Highway 225.

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[a] All times listed are approximate and in Central Time.

[b] ITC deployed its contractor, the Center for Toxicology and Environmental Health (CTEH), to conduct handheld, real-time air monitoring in accordance with two distinct sampling plans: one for the local community and another for the industrial area.

Figure 20. Photo showing plume of black smoke from First & Second 80's tank farm fire. (Credit: The Texas Tribune [18])

From Monday, March 18, through Friday, March 22, 2019, six school districts (Deer Park, La Porte, Pasadena, Channelview, Galena Park, and Sheldon) cancelled classes and activities on some of the days out of an abundance of caution.[a]

On Thursday, March 21, 2019, elevated levels of benzene were detected in the northern portion of Deer Park between 4:02 and 8:23 a.m. following the extinguishment of the tank farm fire. Levels remained below those that would pose any immediate health risk; however, the City of Deer Park issued a second precautionary shelter-in-place order that morning, during which time residents were advised to remain indoors, close all doors and windows, and turn off air conditioning or heating systems to prevent chemical vapors from entering the homes. As a result, the same six local school districts closed all campuses and cancelled all activities for the day [18] Air contaminant levels were resolved roughly five hours after they were initially detected, and the shelter-in-place order was lifted later that morning at approximately 11:40 a.m.

On Friday, March 22, 2019, the containment wall surrounding the First & Second 80's tank farm partially collapsed, allowing a mixture of hydrocarbon and petrochemical products and firefighting foam to release from containment and enter the surrounding waterways. As a result of the release, a seven-mile stretch of the Houston Ship Channel adjacent to the ITC Deer Park terminal was temporarily closed [13]. Additionally, Harris County

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[a] On Monday, March 18, 2019, both Deer Park Independent School District (ISD) and neighboring La Porte ISD cancelled classes and activities for the day, out of an abundance of caution [66]. On Wednesday, March 20, 2019, six local school districts, including Channelview ISD, Deer Park ISD, Galena Park ISD, La Porte ISD, Pasadena ISD, and Sheldon ISD, made the decision to close for the day and cancel all activities, out of an abundance of caution [18]. On Friday, March 22, 2019, Deer Park ISD, La Porte ISD, and Pasadena ISD once again cancelled all classes and activities for the day. [18]

announced the closure of its waterfront parks, as did the City of LaPorte [14]. The release also resulted in elevated levels of VOCs detected in the vicinity of the terminal, which caused the San Jacinto Monument, Battleship Texas State Parks, and the Lynchburg Ferry to temporarily close.

Local waterways and waterfront parks near the terminal remained closed the following week as cleanup operations continued in the surrounding waterways. However, no additional shelter-in-place orders were issued, and all local school districts impacted by the ITC incident reopened campuses on Monday, March 25, 2019, without any further disruption. ITC, Harris County, TCEQ, and the EPA each continued their respective air monitoring activities in the area; no additional elevated levels of benzene or VOCs were detected.

On June 19, 2019, Unified Command partners transitioned this incident from the emergency response phase to the long-term remediation phase. Long-term remediation included ITC's disposal of approximately 387,000 barrels of liquid waste at several disposal facilities. As of October 2019, ITC had also processed approximately 51,700 barrels of fire-related wastewater on-site through its wastewater plant [16].

The Natural Resource Damage Assessment and Restoration Program reported that an estimated 470,000–523,000 barrels of a mixture of fire water, firefighting aqueous film-forming foams, and petrochemical products from the storage tanks were released into Tucker Bayou and adjacent waters, sediments, and habitats. The long-term environmental damage is still under assessment. In February 2022, the Texas Parks and Wildlife Department, TCEQ, Texas General Land Office, U.S. Department of the Interior, and the National Oceanic and Atmospheric Administration (NOAA) published a natural resource damage assessment plan, which is intended to serve as the guiding document for all damage assessment activities related to the March 17, 2019, incident [19].

This incident did not result in any injuries or fatalities. ITC estimated that property damage resulting from the loss of the First & Second 80's tank farm associated with the March 17, 2019, incident exceeded $150 million.

3 TECHNICAL ANALYSIS

This incident occurred when the butane-enriched naphtha product released from the Tank 80-8 circulation pump and found an ignition source, causing a fire to erupt and engulf the tank's piping manifold. Over the next three days, the massive fire spread to 12 additional aboveground storage tanks in the tank farm before emergency responders fully extinguished the flames. Two days later, the secondary containment wall surrounding the tank farm partially collapsed, allowing the mixture of released hydrocarbon products, firefighting foam, and contaminated water in the containment area to release into the surrounding waterways.

As discussed below, the CSB's investigation established that problems with the mechanical integrity of the Tank 80-8 circulation pump enabled the release of the butane-enriched naphtha product and contributed to the fire's cause.

The pump installed in the Tank 80-8 piping manifold at the time of the incident was a *Goulds Model 3196 XLT-X* chemical process pump.[a] The pump consisted of a liquid end and power end, connected by a frame adapter

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[a] According to company records, the circulation pump involved in the incident was first installed in the Tank 80-8 piping manifold around March 2007.

(**Figure 21**). The liquid end was comprised of the casing, impeller, seal chamber, and mechanical seal gland.[a] The mechanical seal was designed to contain the butane-enriched naphtha product inside the seal chamber as it flowed through the pump. The seal gland mounted flush to the seal chamber cover and was secured by four gland nuts threaded onto the seal chamber studs that extended through designated slots on the seal gland. The power end was comprised of the bearing frame, pump shaft, two sets of ball bearings, and oil seals. The purpose of the two sets of ball bearings was to support the pump shaft. The inboard bearing was responsible for carrying radial loads,[b] and the outboard bearing was responsible for carrying both radial and thrust (axial) loads. The pump shaft extended from the impeller through the seal chamber and bearing frame to the motor coupling.

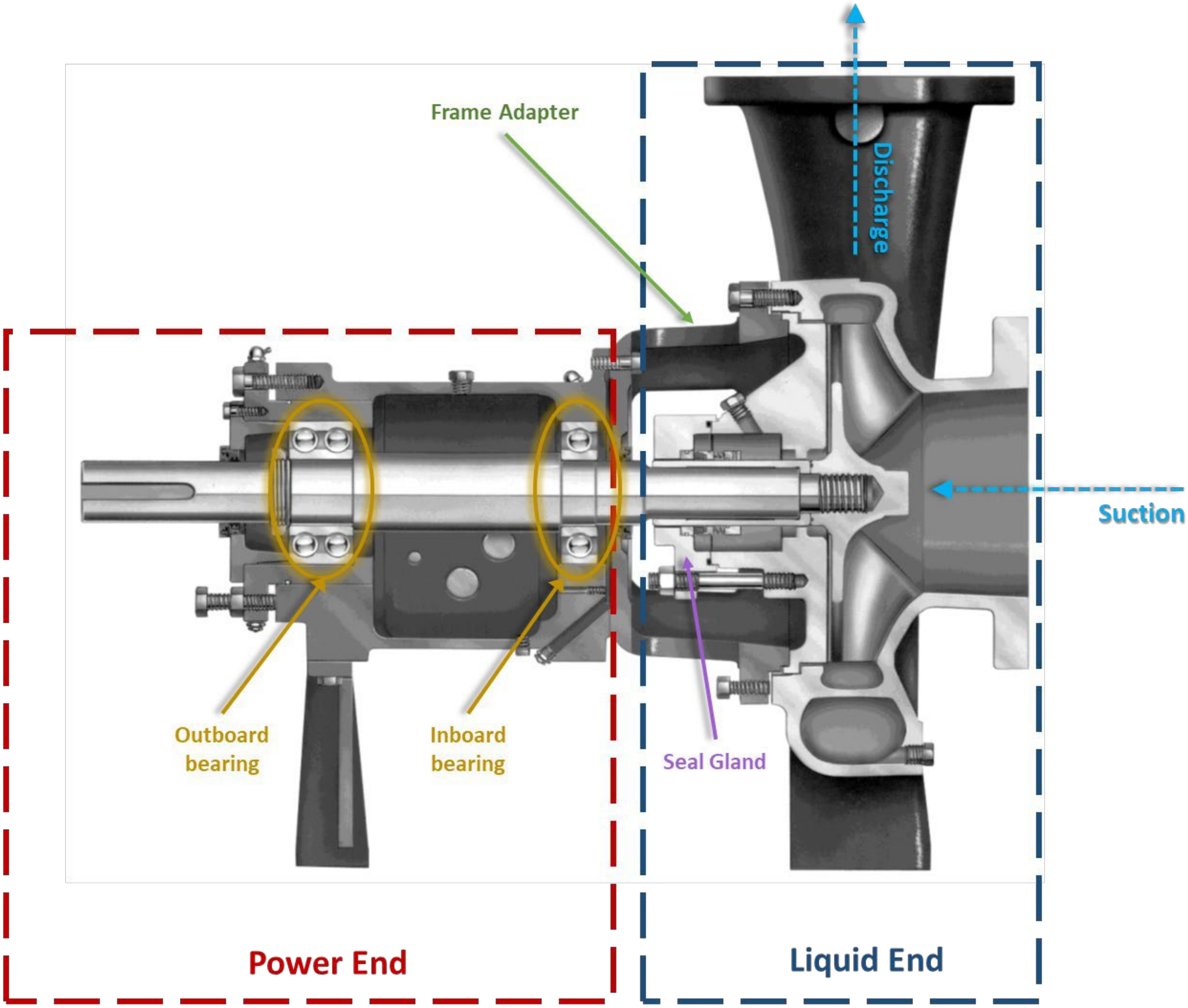

Figure 21. Sectional view of *Goulds Model 3196 XLT-X* chemical process pump. This view identifies the pump's liquid end, power end, and rigid frame adapter. (Credit: *Goulds*, annotations by CSB)

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[a] The seal found in place post-incident was a Chesterton S20™ Tandem Dual Cassette Seal, which was also designed for use with the Goulds Model 3196 XLT-X pump

[b] Radial loads are forces that are perpendicular to the axis of the shaft, parallel to the bearing's radius.

Following the incident, the Tank 80-8 circulation pump skid was transported to a third-party facility for inspection and teardown (**Figure 22**). The pump was fully disassembled to allow for visual examination of its individual components and documentation of their condition. Severe degradation and wear damage were observed on the pump shaft, seal, and outboard bearing. Substantial abrasive wear was visible on the pump shaft adjacent to the seal on the inboard side of the bearing housing (**Figure 23**). Extensive contact wear was also visible on the seal gland (**Figure 24**).

Figure 22. Tank 80-8 pump removed from ITC Deer Park terminal. Pictured is the pump kit on a pallet, as removed from the incident site. (Credit: CSB)

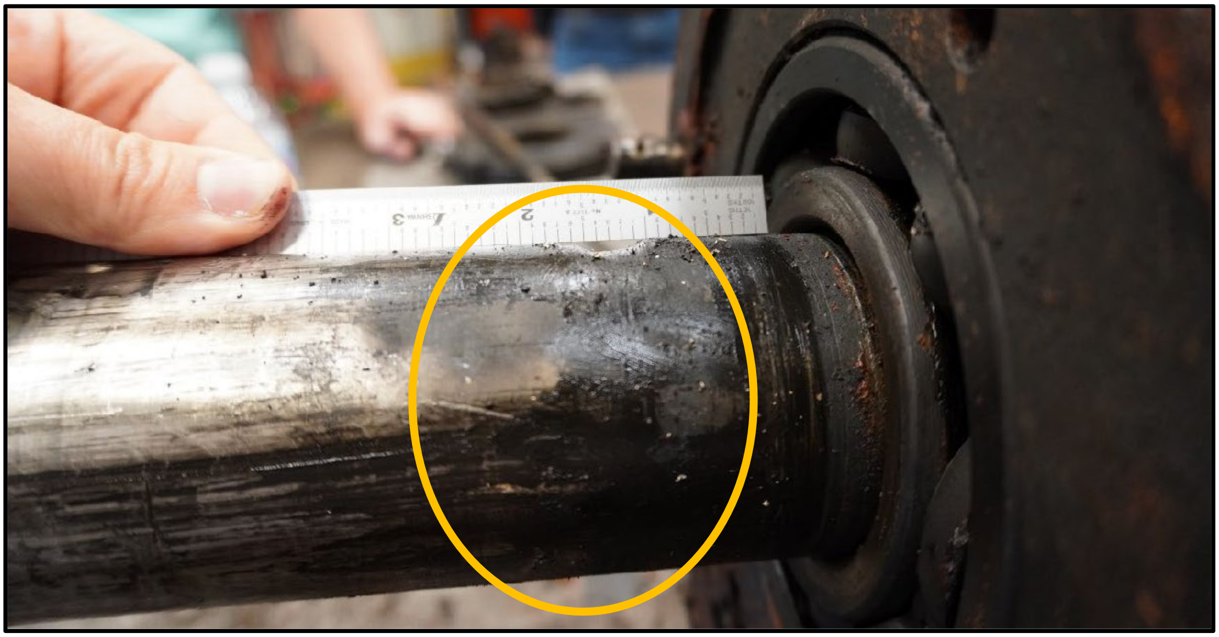

Figure 23. The severe abrasive wear damage observed on the Tank 80-8 pump shaft adjacent to inboard side of bearing housing, on August 30, 2019. (Credit: CSB)

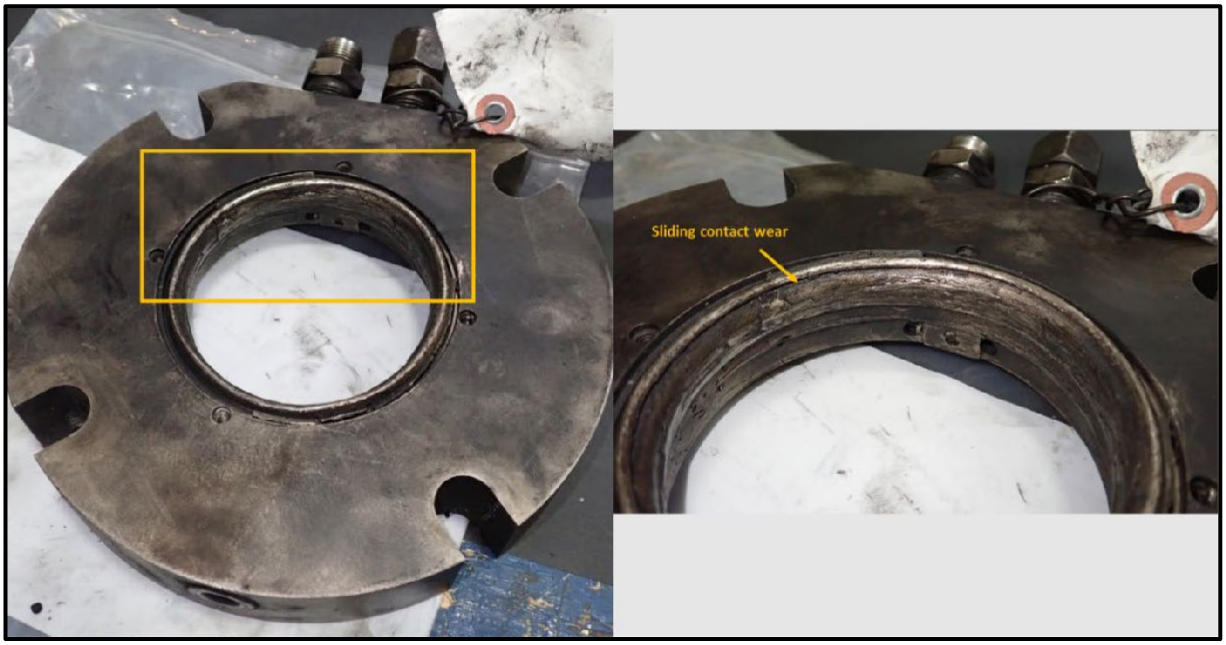

Figure 24. Smeared metal on inside surface of seal gland that indicates sliding contact with the pump shaft. (Credit: Stress Engineering)

Four gland nuts secured the seal gland to the seal chamber cover to prevent the butane-enriched naphtha product from leaking from the pump, as shown in **Figure 25**. Post-incident inspection of the Tank 80-8 circulation pump revealed that none of the four gland nuts remained in place and that the seal gland was completely separated from the seal chamber cover (**Figure 26**). Additionally, the barrier fluid steel tubing used to provide lubrication to the mechanical seal via the seal gland was found severed from the nearby external seal pot and wrapped around the pump shaft.

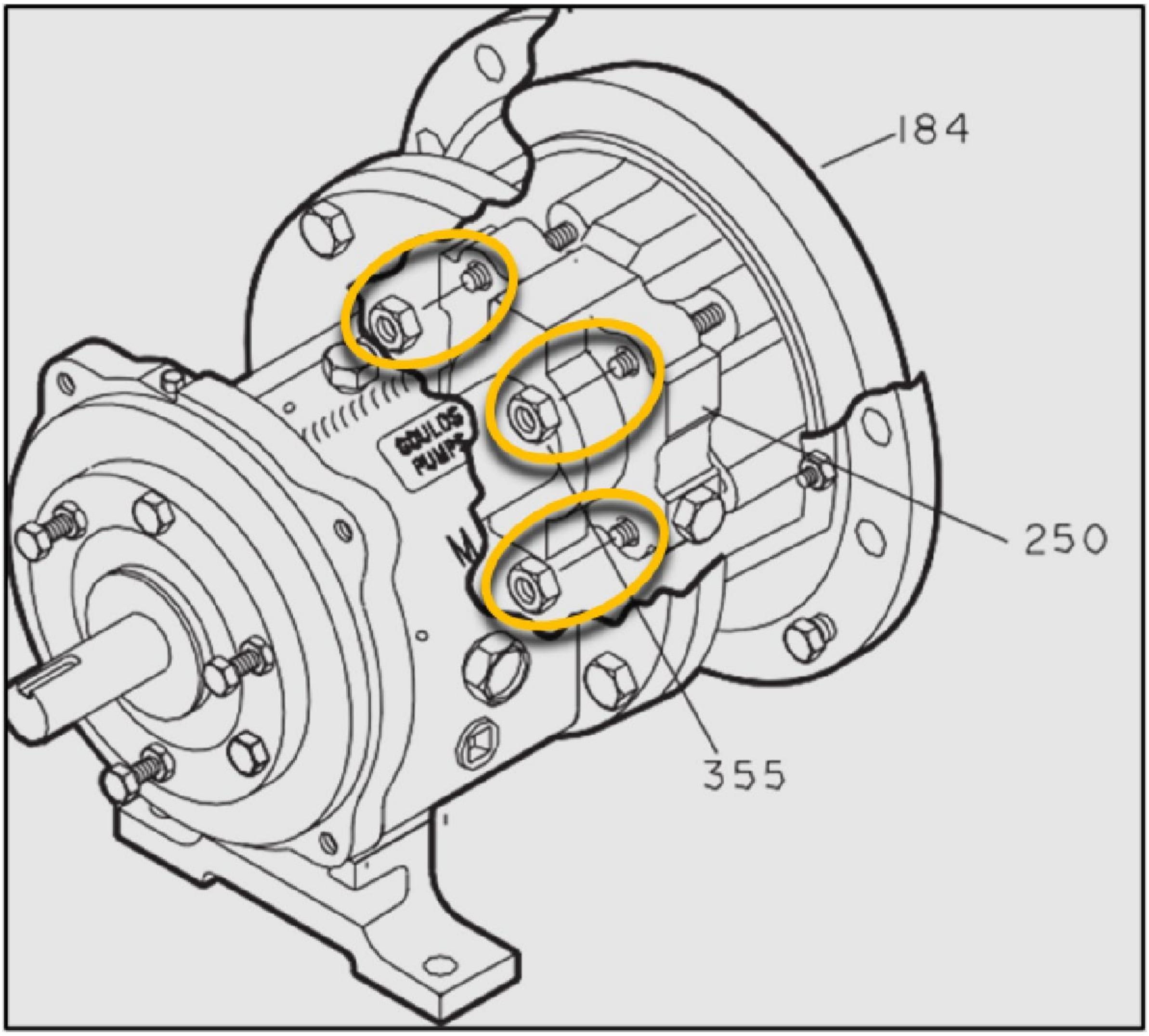

Figure 25. Cutaway drawing of *Goulds* chemical process pump showing the locations of three of the four gland nuts that held the seal gland in place against the seal chamber cover. *Note: fourth gland nut is not visible in drawing*. [Credit: *Goulds*, annotations by CSB]

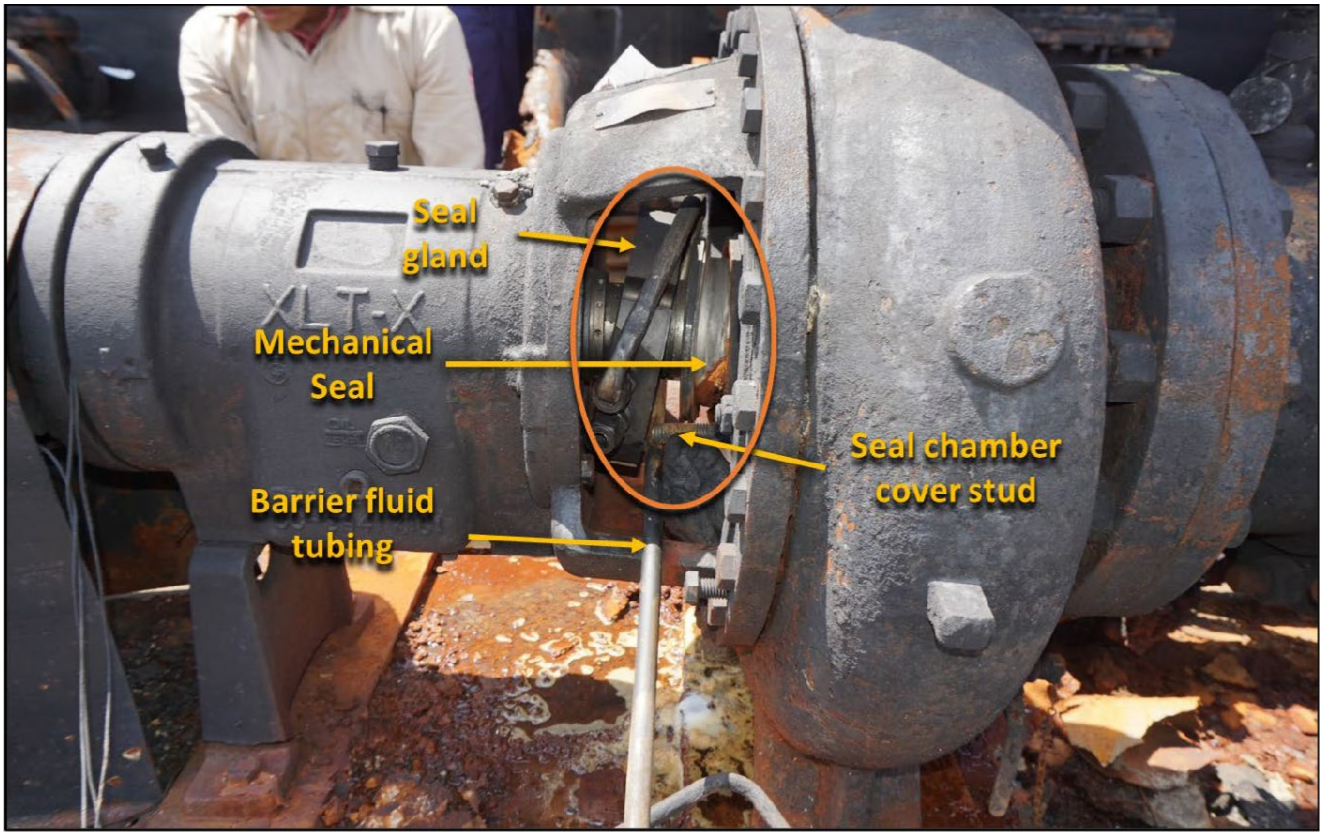

Figure 26. Tank 80-8 circulation pump. This photo shows the point of separation observed between the mechanical seal gland and seal chamber cover where the butane-enriched naphtha product released. (Credit: CSB).

Post-incident examination of the internal threads of the three seal chamber studs that supported the seal gland showed non-uniform deformation around the circumference of the threads that projected through the slots on the seal gland (**Figure 27**). Metallography completed on one of the studs identified flattening of the thread crowns (**Figure 28**).[a] The non-uniform deformation of the threads that projected through the slots on the seal gland and flattening of the thread crowns are indicative of radial compression contact, as opposed to a shear force contact on the threads. Therefore, the damage was likely caused by the seal chamber studs making vibrational contact with the seal gland slots as the gland nuts loosened and eventually released from the studs. Based on the post-incident condition of the pump, the CSB concludes that the butane-enriched naphtha product release initiated when the Tank 80-8 circulation pump's gland nuts loosened from the seal chamber cover, allowing the seal gland to separate from the seal chamber cover and consequently creating a path for butane-enriched naphtha product to release.

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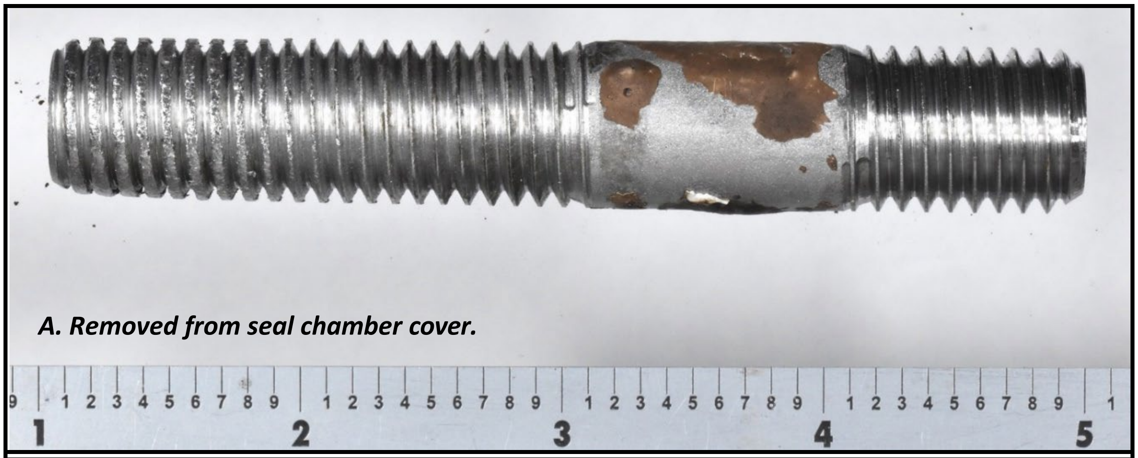
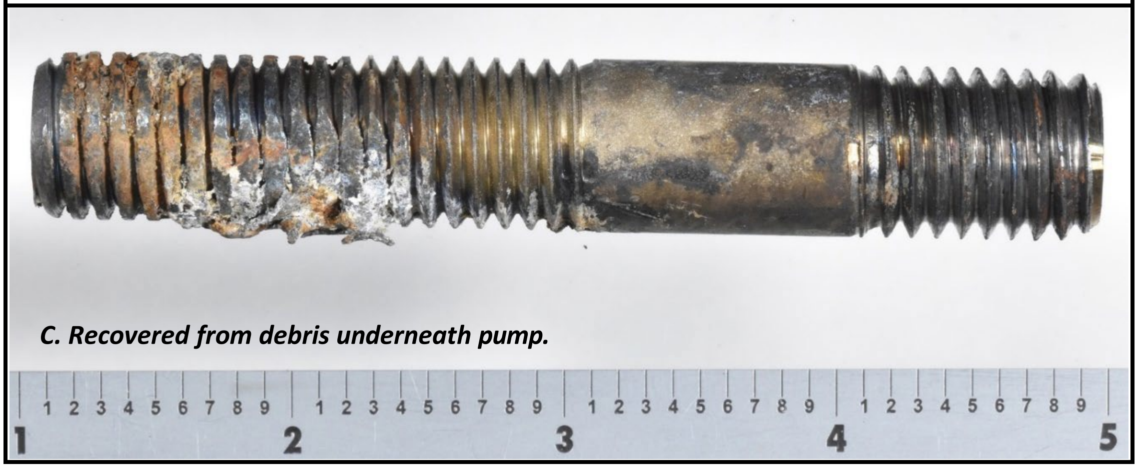
[a] The internal threads of the blind holes in which the studs were located, as well as the threads on the studs where they engaged the blind holes, were in good condition.



A. Removed from seal chamber cover.

B. Found loose inside frame adapter.



C. Recovered from debris underneath pump.

Figure 27. Three seal chamber cover studs recovered from Tank 80-8 circulation pump, post-cleaning. The longer threaded ends passed through the slots in the seal gland, while the shorter threaded ends were engaged in the seal chamber cover. (Credit: Stress Engineering)

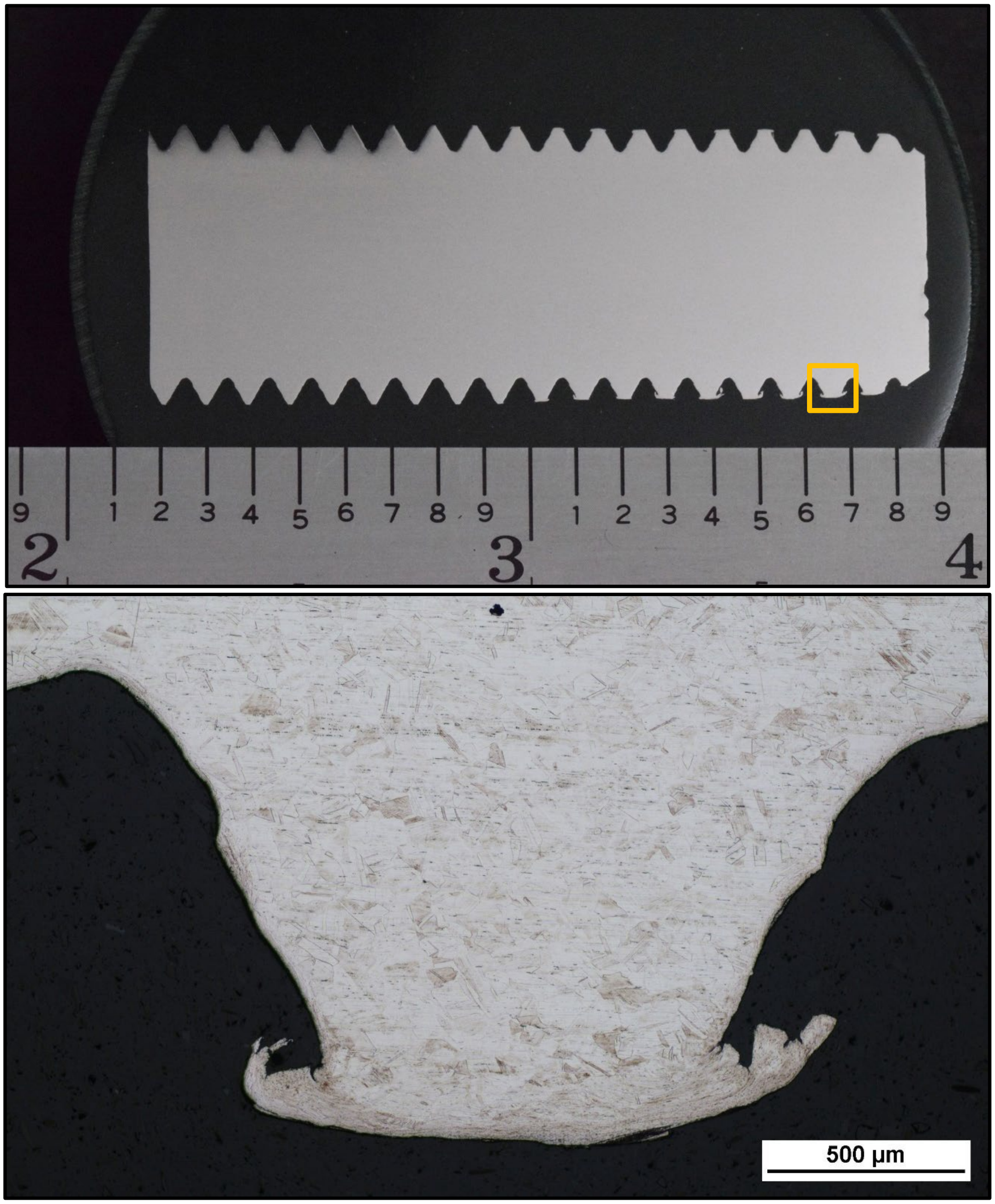


Figure 28. Section of threads from seal chamber stud that projected through slots in seal gland, where flattening of the thread crowns was observed (Credit: Stress Engineering)

Prior to disassembly of the Tank 80-8 circulation pump, radial displacement of the pump shaft was observed on the outboard side on the bearing frame, which is typically indicative of extensive bearing failure. Subsequent disassembly of the bearing housing confirmed failure of the outboard thrust bearing.

The Tank 80-8 circulation pump was in operation on the morning of March 17, 2019. Once the outboard bearing failed, the pump shaft would have been left largely unsupported, which in turn would have allowed extensive upward deflection on the outboard end of the pump shaft (due to the weight of the impeller on the inboard end of the pump shaft) and shaft centerline misalignment. As the Tank 80-8 circulation pump continued to operate under these conditions, the high-speed rotation of the largely unsupported pump shaft likely induced significant vibration in the pump, which increased as the misalignment amplified. Beginning at approximately 9:30 a.m. that morning, the recorded tank volume began to decrease and the average flow rate for the tank began to increase with no intended change in operation having occurred. This was likely the result of the gland nuts loosening from the seal chamber studs, which allowed the seal gland to separate from the seal chamber cover, consequently creating an opening for butane-enriched naphtha product to release from the pump.[a] Based on the extensively degraded condition of the outboard thrust bearing and the seal chamber studs observed post-incident, the CSB concludes that Tank 80-8's circulation pump likely continued to operate past the point of outboard bearing failure while circulating the butane-enriched naphtha product. The bearing failure likely led to significant pump vibration, which loosened the gland nuts that secured the mechanical seal in place, causing the seal to separate and allow the release of the flammable mixture.

The Tank 80-8 circulation pump continued to operate as the butane-enriched naphtha product released from the failed pump to the atmosphere for roughly 30 minutes before the fire erupted at about 10:00 a.m. During this time period, approximately 200 barrels (8,400 gallons) of the butane-enriched naphtha product accumulated in the area around the pump in the Tank 80-8 piping manifold. Due to the high vapor density of the hazardous substance, the butane-enriched naphtha product's flammable vapors likely hovered near ground level and collected in low-lying areas around the Tank 80-8 pump skid. There was no vibration monitoring system installed on the Tank 80-8 circulation pump nor was there an LEL gas detection system in the area to alert personnel of the ongoing release.

As the pump shaft continued to rotate, the high-speed grinding of the two metal surfaces caused a groove to form on the pump shaft near the inboard side of the bearing housing. The depth of the groove on the pump shaft created by the metal-to-metal contact indicates the pump continued to operate for several minutes after the seal gland fully separated from the seal chamber cover (**Figure 23**). The CSB concludes that accumulated flammable vapors in the area around the Tank 80-8 pump skid were likely ignited as a result of heat generated from the metal-to-metal contact between the unrestrained seal gland and pump shaft.

4 SAFETY ISSUES

The following sections discuss the safety issues contributing to the incident, which include:

- **Pump Mechanical Integrity.** ITC did not have a formal mechanical integrity procedure in place that defined requirements for maintaining the mechanical integrity of Tank 80-8 and its associated equipment, including the Tank 80-8 circulation pump. A formal mechanical integrity program for pumps in highly hazardous chemical service could have prevented this incident by providing ITC with additional opportunities to identify pump issues prior to the incident. The mechanical seal on the pump failed on March 17, 2019, allowing butane-enriched naphtha product to release from the pump while it continued to operate.

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[a] The combined pressure of flowing butane-enriched naphtha product and motion of the pump shaft would have caused the unrestrained seal gland to propel forward, strike the inboard side of the bearing frame, and rotate once around the pump shaft, as evidenced by the barrier fluid tubing that was found severed and wrapped itself around the pump shaft. Once this occurred, the forward edge of the unrestrained seal gland had come to rest against the rotating pump shaft (**Figure 26**).

- **Flammable Gas Detection Systems.** Tank 80-8 was not equipped with a flammable gas detection system to warn personnel of a hazardous atmosphere resulting from loss of containment from the tank or its associated equipment. In 2014, a hazard review team recommended the addition of flammable gas detection systems near Tank 80-8; however, ITC did not implement this recommendation and did not document why it was not implemented. In the absence of a flammable gas detection system, there were no alarms to alert personnel about the initial release of butane-enriched naphtha product around the Tank 80-8 piping manifold. Consequently, the butane-enriched naphtha product continued to release from the failed pump for approximately 30 minutes, completely undetected, before its flammable vapors eventually ignited.

- **Remotely Operated Emergency Isolation Valves.** Tank 80-8 and the other aboveground storage tanks located in the First & Second 80's tank farm were not equipped with ROEIVs designed to mitigate process releases remotely from a safe location. The primary drivers for identifying the need for this type of equipment would have been through implementation of hazard assessments, such as those required by of the OSHA PSM standard and the EPA RMP rule, as well as insurance company audits and/or corporate risk evaluations results. On the day of the incident, the large volume of butane-enriched naphtha product contained in Tank 80-8 could not be remotely or automatically isolated, and it continued to release, via the failed pump, fueling the fire that continued to intensify around the tank. As the Tank 80-8 fire intensified, flames from the fire spread to adjacent tank piping manifolds in the tank farm and eventually compromised the equipment, causing breaches in piping that allowed the hydrocarbon and petrochemical products contained in the storage tanks to release into the common containment area.

- **Tank Farm Design.** Although the First & Second 80's tank farm was designed largely in accordance with applicable NFPA 30 requirements, elements of the tank farm design, including tank spacing, subdivisions, engineering controls for pumps located inside the containment area, and drainage systems, made it difficult for emergency responders to slow or prevent the spread of the initial fire, and allowed the fire to spread to other tanks within the tank farm. While NFPA 30 defines minimum requirements for tank farm design, additional industry guidance documents provides more robust tank farm design recommendations. While ITC was not required to implement additional industry guidance recommendations, many of which were developed after construction of the First & Second 80's tank farm, implementation of such recommendations could have prevented the escalation of this incident.

- **PSM and RMP Applicability.** ITC did not apply a formal process safety management program to Tank 80-8 because neither the OSHA PSM standard nor the EPA RMP rule applied to Tank 80-8 and its associated equipment. Tank 80-8 was not covered by the OSHA PSM standard due to the atmospheric storage tank exemption in the standard, and the EPA RMP rule did not apply due to the flammability rating exemption in the rule for the butane-enriched naphtha mixture. Although ITC applied some process safety management elements across the terminal, the company did not apply other key elements, such as Mechanical Integrity and Process Hazard Analysis, to atmospheric storage tanks in highly hazardous chemical service. Applying these elements would have provided the company with additional opportunities to identify and control hazards through multiple layers of protection, including the examples of preventative and mitigative safeguards discussed in this report. Thus, had ITC developed and implemented a comprehensive process safety management program that effectively identified and controlled hazards for Tank 80-8 and its related equipment, the incident could have been prevented.

4.1 PUMP MECHANICAL INTEGRITY

The American Petroleum Institute (API) defines mechanical integrity as the management of critical process equipment to ensure it is designed and installed correctly and that it is operated and maintained properly [20, p. 4]. Mechanical integrity is an asset management program that encompasses the actions or activities needed to ensure that process equipment is designed, fabricated, installed, operated, and maintained throughout its service life so that it can safely and reliably provide the desired performance. Properly managing and maintaining process equipment reduces the likelihood of unexpected equipment failure resulting from inadequate or infrequently performed maintenance.

4.1.1 MECHANICAL INTEGRITY PROGRAM

ITC has a *Mechanical Integrity* procedure (ITC-08-A-3.06) in place for certain equipment at its Deer Park terminal. The procedure defines requirements for maintaining the mechanical integrity of equipment used to handle and store chemicals regulated by the OSHA PSM standard and/or EPA RMP rule. It is also intended to establish management systems to ensure compliance with these standards. The defined scope of the ITC procedure states:

> "*The requirements of this procedure apply to equipment handling or storing chemicals at the ITC Deer Park and Pasadena facilities identified in Regulated Chemicals Table ITC-08-A-a7 and any others identified by Senior Management. The equipment includes but is not limited to:*
>
> - *Pressure vessels and storage tanks;*
> - *Piping systems (including piping components such as valves);*
> - *Relief and vent systems and devices;*
> - *Emergency shutdown systems;*
> - *Controls (including monitoring devices and sensors, alarms, and interlocks) and,*
> - *Pumps.*"

Under the "equipment requirements" section of the procedure, specific requirements are listed for pressure vessels and storage tanks, piping systems, relief and vent systems and devices, emergency shutdown systems, and controls. The requirements include inspection frequency or intervals for each type of equipment, and in some cases the specific procedures that maintenance personnel are expected to use to complete the relevant inspection or testing. The equipment requirements section of the procedure does not, however, include any specific requirements for pumps, even though they are listed as included equipment in the scope.

Furthermore, the requirements contained in ITC's *Mechanical Integrity* procedure are only applicable to equipment handling or storing chemicals identified in the *ITC Regulated Chemicals Table.* According to the referenced table, neither naphtha nor butane is listed as a regulated chemical at the ITC Deer Park terminal. ITC also took the position that Tank 80-8 and its associated equipment to be covered under the OSHA PSM standard based on the flammable liquid atmospheric storage tank exemption (further discussed in Section 4.5.1).[a] As such, Tank 80-8 and its associated equipment were not subject to the ITC Deer Park terminal's *Mechanical Integrity* procedure.[b] The OSHA PSM standard and EPA RMP rule exemptions are further discussed in Section 4.5.

The OSHA PSM standard's Mechanical Integrity element includes specific requirements for 1) establishing and implementing written procedures to maintain process equipment, 2) training employees involved in maintaining process equipment, 3) performing inspections and tests on process equipment at specified frequencies, 4) correcting deficiencies in process equipment, and 5) quality assurance, which includes performing checks to ensure that equipment is installed properly and that maintenance materials and spare parts are suitable for the relevant process application. In the case where a company does not consider the OSHA PSM standard to be applicable to certain equipment, it could rely on voluntary guidelines, such as the Center for Chemical Process Safety's (CCPS's)[c] *Guidelines for Risk Based Process Safety (RBPS)* to design and implement an effective process safety management program to manage risks at its facilities. The RBPS Guidelines are not mandatory, but they are intended to help organizations design and implement more effective process safety management systems [21].

Approximately three months prior to the incident, on December 4, 2018, ITC removed the Tank 80-8 circulation pump from service due to a report of the pump "making a loud noise," with the pump's bearing housing observed to be shaking and vibrating. Maintenance personnel rebuilt the pump at the maintenance shop, using some spare parts, and reinstalled it onto the existing pump skid.[d] This rebuild work included the installation of new inboard and outboard bearings and a new mechanical seal, which were the same parts that failed during the March 17, 2019, incident.[e,f] Following the pump replacement in December 2018, no additional noise issues involving the Tank 80-8 circulation pump were reported to the maintenance department, and the pump appeared to operators to be operating normally the night before the incident.

Although the CSB could not ascertain the cause(s) of the Tank 80-8 circulation pump failure on March 17, 2019, the CSB identified the following mechanical integrity elements that could have reduced the likelihood of the

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[a] 29 CFR § 1910.119(a)(1)(ii)(B)

[b] As discussed in detail in Section 4.5.1.2, following the March 2019 incident, OSHA cited the ITC Deer Park terminal for violation of the PSM standard. OSHA and ITC eventually entered into a settlement agreement, whereby ITC paid the penalties for the alleged violations and agreed to conduct an enhanced abatement at the ITC Deer Park terminal. However, in the settlement ITC did not concede its belief that Tank 80-8 was exempt from coverage under the OSHA PSM standard, and the PSM compliance related language was removed from the citations.

[c] The American Institute of Chemical Engineers (AIChE) created the CCPS in 1985 after the chemical disasters in Mexico City, Mexico, and Bhopal, India, to develop and disseminate technical information for use in the prevention of major chemical accidents [82].

[d] Maintenance personnel positioned the pump on the existing pump skid and slid it into place against the existing pump casing gasket. Once in position, maintenance personnel bolted the frame adapter to the pump casing, bolted the pump feet to the pump skid, set the clearance, filled the external seal pot, and pressure tested the pump using plant nitrogen. They then used the straight edge method to verify motor/pump alignment before re-coupling the replacement pump with the motor.

[e] Maintenance personnel commonly referred to the seal chamber as the "stuffing box." According to personnel, it is an old industry or slang term that came about since they used to stuff packing into the chamber, as opposed to seals, which are used today.

[f] Maintenance personnel disassembled the power end of the pump and used a wire brush to remove surface rust from the ductile iron surfaces, checked fit and tolerances on the bearing housing, and cleaned the pump shaft. Once they verified that all parts of the power end were in good condition, they pressed new inboard and outboard bearings on the pump shaft, inserted the pump shaft assembly in the bearing housing, and installed new labyrinth seals on both ends of the assembled bearing housing. Maintenance personnel cleaned the parts, checked tolerances, set a new mechanical seal in the seal chamber, and used the gland nuts to fasten the seal gland to the seal chamber cover.

Tank 80-8 circulation pump's outboard bearing failure that caused the mechanical seal to separate on the day of the incident:

- ITC did not have a written pump rebuild or replacement procedure in place that referenced the pump manufacturer's recommended instructions to ensure a proper installation of the Tank 80-8 circulation pump when it was rebuilt in December 2018.[a]
- ITC did not provide maintenance personnel with formal, documented training related to pump maintenance and repair work and did not have a formal program in place to assess their competency.[b]
- ITC did not have a formal Preventative Maintenance (PM) program[c] in place for the Tank 80-8 circulation pump that included routine maintenance and inspection activities recommended by the pump manufacturer.[d]
- ITC did not have a quality assurance program in place at the ITC Deer Park terminal to allow it to confirm the origin of replacement parts used in the rebuild of the failed Tank 80-8 circulation pump.

ITC uses similar style pumps throughout its Deer Park terminal to facilitate the movement of process materials. Based on the company's reliance on this type of rotating equipment to move large volumes of hazardous substances throughout the terminal, ITC should take necessary measures to ensure the mechanical integrity of its pumps so that they operate safely, perform as designed, and do not unexpectedly fail and release hazardous substances to the environment, regardless of whether the OSHA PSM standard or EPA RMP rule are applicable to the equipment. Specifically, ITC's *Mechanical Integrity* procedure, which is currently only applicable to PSM- and RMP-covered equipment, should include specific requirements for maintaining the mechanical integrity of pumps at the terminal, like the requirements listed in the procedure for pressure vessels and storage

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[a] Maintenance personnel told CSB investigators that the company did not have a written pump replacement procedure, but they were aware of and *could* reference the *Goulds Installation, Operation, and Maintenance (IOM) Instructions,* as needed, when rebuilding and replacing a pump. However, there was no requirement for maintenance personnel to use these instructions, as pump rebuilds and replacements were considered routine. Accordingly, maintenance personnel did not follow the pump alignment procedure outlined in the *Goulds IOM Instructions*. For example, instead of using the dial indicators referenced in the *Goulds IOM Instructions,* maintenance personnel typically used either a laser alignment tool or the straight edge method to complete pump alignments at the ITC Deer Park terminal. Maintenance personnel explained that they used the straight edge method in this instance because they had already installed the necessary shims to ensure proper alignment when the existing pump was first installed nearly 12 years earlier, in March 2007.

[b] ITC hires individuals with experience in relevant areas of expertise, and maintenance personnel receives training through shadowing other personnel and participating in vendor training programs. Not all of the maintenance personnel employed with ITC at the time of the incident listed having past experience with pumps or rotating equipment on their training records or application materials. Further, maintenance personnel did not receive any formally documented training directly related to pumps or other rotating equipment. Instead, they received much of their training through shadowing other personnel in the field and participating in vendor training programs, as applicable. Regardless, they were all deemed to demonstrate an adequate level of competency to perform the duties associated with their role and were expected to maintain and repair pumps and rotating equipment throughout the ITC Deer Park terminal.

[c] ITC routinely monitored the physical condition of pumps at the ITC Deer Park terminal as part of biweekly maintenance walkthroughs and completed reactive maintenance on the pumps based on observations made during the walkthroughs. The company did not, however, have a preventative maintenance program in place for its pumps that included the *Goulds* recommended maintenance schedule. According to maintenance personnel, the only work order generated through the maintenance planning system for Tank 80-8 pump maintenance was one to change out both the bearing frame and seal pot oil on an annual basis.

[d] The *Goulds IOM Instructions* for the Tank 80-8 circulation pump states that a routine maintenance program can extend pump life and asserts that "well maintained equipment will last longer and require fewer repairs." Additionally, the document provides a recommended "Routine Maintenance Schedule" for its customers that includes routine maintenance items to monitor, including bearing lubrication, seal monitoring, vibration analysis, discharge pressure, and temperature monitoring. The recommended maintenance schedule in the *Goulds IOM Instructions* also includes recommended routine, three-month, and annual inspection items for its customer's maintenance personnel to perform.

tanks, piping systems, relief and vent systems and devices, emergency shutdown systems, and controls. The CSB concludes that the ITC Deer Park terminal's management systems lacked essential mechanical integrity program items, such as maintenance procedures, training for pump replacements and rebuilds, and routine preventative maintenance activities as recommended by the pump manufacturer, for equipment in highly hazardous chemical service that was not covered by OSHA PSM or EPA RMP requirements. A formal mechanical integrity program for all pumps in highly hazardous chemical[a] service could have prevented this incident by allowing ITC to have additional opportunities to identify Tank 80-8's circulation pump issues prior to the incident. A mechanical integrity program is part of a comprehensive process safety management system (further discussed in Section 4.5). Accordingly, the CSB recommends that ITC develop and implement a process safety management system for the ITC Deer Park terminal applicable to all atmospheric storage tanks and associated equipment in highly hazardous chemical service. The program should follow industry guidance provided in publications such as the American Petroleum Industry's API STD 2610, *Design, Construction, Operation, Maintenance, and Inspection of Terminal and Tank Facilities* and the Center for Chemical Process Safety's *Guidelines for Risk Based Process Safety*. (**2019-01-I-TX-R1**)

4.1.2 CONDITION MONITORING

Condition monitoring can be a proactive method to identify pump issues before a pump is severely damaged, which in turn can help prevent hazardous chemical releases. One of the most common methods of condition monitoring for rotating equipment is vibration monitoring and analysis, which can help detect issues such as imbalance, misalignment, bearing issues, and looseness [22]. Vibration can be detected in a variety of ways, ranging from basic handheld collectors to more sophisticated networked systems. In many chemical and petrochemical facilities, a baseline vibration program with monthly vibration monitoring may help flag problems long before a pump nears deterioration, allowing maintenance departments to minimize pump repair costs. Some companies equip their pumps with online condition monitoring systems that detect operating parameters in real time and alert the operators to abnormal conditions through alarms. In describing how condition monitoring relates to predictive maintenance, one author writes, "while machinery failure may be unpredictable, emerging failure is detectable" [23].

The Tank 80-8 circulation pump was not equipped with a condition monitoring system capable of detecting excess vibration in the equipment. Additionally, ITC did not have a vibration monitoring practice or program in place for the pump at the time of the incident aside from biweekly maintenance walkthroughs where operators identified vibration issues from equipment noise or leaks.

Based on the condition of the Tank 80-8 circulation pump bearings observed during post-incident inspection and testing, condition monitoring equipment, like the options discussed above, may have detected vibration readings outside of the established limits. In turn, these readings should have triggered an alarm to alert personnel that there was an issue that needed to be investigated. Thus, the CSB concludes that ITC did not retrofit the Tank 80-8 circulation pump with vibration monitoring equipment, which resulted in pump vibration going undetected and allowed the outboard bearing to continue to degrade to failure. Had ITC installed vibration monitoring equipment on the Tank 80-8 circulation pump, excessive vibration likely would have triggered an alarm, and

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[a] The PSM standard defines "highly hazardous chemical" as "a substance possessing toxic, reactive, flammable, or explosive properties…" 29 C.F.R. § 1910.119(b).

ITC operators could have shut down the pump before the bearing failed, preventing the butane-enriched naphtha product release.

The American National Standards Institute (ANSI) American National Standard for Rotary Pumps – Guidelines for Condition Monitoring (ANSI/HI 9.6.9–2018) [25][a] is intended to give pump users a tool for condition monitoring of rotary positive displacement pumps. The document discusses several indicators that may be monitored or reviewed on rotary pumps to predict and identify pump failure modes [25, p. 1].

When the Tank 80-8 circulation pump was originally purchased from *Goulds*, the pump manufacturer did not offer the option of built-in condition monitoring capability for the equipment. However, aftermarket condition monitoring equipment was available from various sources, so ITC could have purchased the equipment and outfitted the pump with continuous condition monitoring capabilities.[b]

Since the time of the incident, ITC has begun installing sensors on pumps at its Deer Park terminal. According to ITC, the equipment will allow operators working in the field to access and monitor pump vibration, temperature, and run-time data. To date, a total of 110 pumps at the terminal have been equipped with sensors. Incorporating condition monitoring technology on all pumps throughout the ITC Deer Park terminal should allow personnel to proactively identify and address potential issues with the pumps, as opposed to identification after failure, as was the case with the Tank 80-8 circulation pump. As such, the CSB recommends that ITC develop and implement a condition monitoring program for all pumps in highly hazardous chemical service at the ITC Deer Park terminal. Ensure that condition monitoring equipment is programmed with control limits, including but not limited to vibration, consistent with ANSI/HI 9.6.9.-2018, that trigger alarms when control limits are exceeded, and that operating procedures and training reflect the appropriate actions to take when an alarm is triggered. (**2019-01-I-TX-R2**)

4.2 FLAMMABLE GAS DETECTION SYSTEMS

Gas detection systems are implemented in many process industries to protect personnel, property, and neighboring communities from the potential consequences of an accidental release. For example, flammable gas detection systems trigger alarms whenever a specified concentration of a flammable gas or vapor is exceeded to provide early warning to personnel so that actions may be taken to prevent the formation and ignition of flammable gas mixtures.[c] In some cases, these alarms may also prompt activation of interlocks or other protective devices to prevent further product release. API Standard 2610, *Design, Construction, Operation, Maintenance, and Inspection of Terminal and Tank Facilities* (API STD 2610), a voluntary industry standard,

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[a] ANSI/HI 9.6.9-2018 was sponsored and published by the Hydraulic Institute.

[b] As technology has evolved since 2006, *Goulds* now offers an updated power end called the *Goulds 3196 i-FRAME® power end*, which includes an *i-ALERT*® device integrated in the unit. The *i-ALERT*® device constantly monitors the condition of the pump's bearings to ensure that they are running within established temperature and vibration limits. Whenever a deviation from these limits is detected, the device visually alarms with red flashing lights to alert operators of the recognized abnormal conditions. *Goulds* also now offers the *i-ALERT*® *2* equipment health monitor, which makes condition monitoring possible on virtually any piece of equipment. The *i-ALERT*® *2* is a Bluetooth-enabled device that can be affixed to pumps or other equipment to provide monitoring and diagnostic capabilities to the equipment.

[c] There are various technologies to detect combustible gases/vapors that are widely used [67, p. 293]. Typical application for flammable gas detection systems include pump seals and flanges for hydrocarbon detection and in bulk storage areas [68, p. 32]. Flammable gas detectors should be positioned at low points or near ground level since flammable vapors are typically heavier than air and tend to remain close to the ground.

mentions use of flammable gas detection systems in its discussion of emergency shutdown systems and procedures in terminal and tank facilities: “When fire protection or vapor-detection systems are activated, they should automatically activate the emergency shutdown system” [25, p. 37].

Tank 80-8 was not equipped with a flammable gas detection system to warn personnel of a hazardous atmosphere resulting from loss of containment from the tank or its associated piping manifold equipment. The two most recent property insurance surveys[a] conducted at the ITC Deer Park terminal indicate that gas detection capability existed elsewhere at the terminal at the time of the incident. The survey conducted on April 10, 2017, indicates that LPG storage and light hydrocarbon handling areas in the terminal were equipped with combustible gas detectors. The survey conducted on October 25, 2018, indicates that LPG storage areas and butadiene vessels at the terminal were also equipped with gas detection systems.

ITC indicated that the company had *“an ongoing program and associated recurring annual budget for installation of LEL monitors in areas at the Deer Park facility based on process hazard analyses (PHAs) that identify the potential risk associated with a product leak in that area.”* Since the OSHA PSM standard and EPA RMP rule did not apply to Tank 80-8, ITC was not required to formally perform a PHA on this system at least once every five years. According to available documentation, Tank 80-8 did not have an initial PHA and was not on a recurring PHA cycle. In addition, prior to the incident, the company had not scheduled installation of a flammable gas detection system in the vicinity of the Tank 80-8 piping manifold.

Although the OSHA PSM standard and EPA RMP rule did not apply to Tank 80-8, ITC used its MOC process to document the Tank 80-8 Truck Butane Injection System project.[b] Prior to implementation of the Tank 80-8 truck butane injection system, ITC completed a hazard review for the project as part of this MOC. The project team used the Hazard and Operability (HAZOP)[c] technique to identify the hazards and consequences associated with operation of the proposed truck butane injection system. The team recognized that one of the hazards

KEY LESSON

Terminals and storage tank facilities that handle large volumes of flammable or highly hazardous substances should implement flammable gas detection systems to protect personnel, property, and neighboring communities from the potential consequences of an accidental release. These types of systems should be installed in areas around pumps, seals, flanges, and other common leak locations. These systems should be adequately designed, maintained, inspected, and tested to ensure reliability. Inspection and testing frequencies must be established to ensure the system provides adequate warning of the presence of flammable substances.

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[a] These surveys provided a qualitative risk assessment of the assets and operation of the ITC Deer Park terminal for the purpose of property damage and business interruption insurance loss prevention. They also provided recommendations for areas for improvement from an insurance perspective.

[b] Although parts of the ITC Deer Park terminal were not covered under the OSHA PSM standard, the company applied some elements of PSM, including MOC, to the entire terminal.

[c] HAZOP is a systematic qualitative technique to identify process hazards and potential operating problems using a series of guide words to study process deviations [84].

KEY LESSON

While most hazard and risk assessments consider the risk of single failures at a time, it is important for companies to realize that major incidents happen when multiple failures occur. To prevent these catastrophic events from occurring, companies should ensure the appropriate number of layers of protection are in place to mitigate the likelihood and reduce the severity of events when they do occur. Therefore, when determining when, how, or whether to complete the recommendations from hazard assessments, companies should ensure the appropriate number of preventative and mitigative safeguards are in place such that a single failure of a preventative or mitigative safeguard will not result in a catastrophic event. Leadership should ensure adequate safeguards are in place, as soon as practicable, for hazards identified by the team, especially when engineering controls are recommended and not yet installed.

involved with product storage and circulation was potential loss of containment, the consequences of which were product release, fire, explosion, exposures, injuries, and fatalities. They identified several potential safeguards, including flammable gas detection, that, if implemented, lowered the risk ranking from high to medium. As a result, the project team recommended that ITC "consider projects for LEL meters/deluge at pumps" however, ITC ultimately decided not to install an LEL detector or deluge system at the Tank 80-8 circulation pump and did not document a justification for not implementing this safety recommendation. The CSB concludes that had Tank 80-8 been subject to the OSHA PSM standard and/or the EPA RMP rule, ITC would have been required to track the recommendation to install a flammable gas detection system such as an LEL detector or deluge system at the Tank 80-8 circulation pump to completion and document the resolution in a timely manner.[a]

On the day of the incident, there was no flammable gas detection system in the area, and the release of butane-enriched naphtha product from the failed Tank 80-8 circulation pump did not trigger any alarms in the area to alert personnel in the CCR of the initial release of flammable material around the Tank 80-8 piping manifold. Consequently, butane-enriched naphtha product continued to release from the failed pump for approximately 30 minutes, completely undetected, before its flammable vapors eventually ignited. The CSB concludes that had a flammable gas detection system existed in the vicinity of the Tank 80-8 circulation pump, it could have provided adequate time for personnel to detect and attempt to secure the butane-enriched naphtha product release before its flammable vapors eventually ignited.

The CSB recommends that ITC install flammable gas detection systems with associated alarm functions in product storage and transfer areas at the ITC Deer Park terminal where flammable substance releases could occur. Develop

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[a] 29 C.F.R. § 1910.119(e)(5): "The employer shall establish a system to promptly address the team's findings and recommendations; assure that the recommendations are resolved in a timely manner and that the resolution is documented; document what actions are to be taken; complete actions as soon as possible; develop a written schedule of when these actions are to be completed; communicate the actions to operating, maintenance and other employees whose work assignments are in the process and who may be affected by the recommendations or actions."

and implement a response plan and operator training for actions to take when an alarm sounds. (**2019-01-I-TX-R3**)

Since the incident, ITC has expanded its ongoing program of risk-based installation of LEL monitors/flammable gas detectors throughout the ITC Deer Park terminal. According to the company, ITC has installed 196 additional LEL monitors/flammable gas detectors at the terminal, through March 2023, as part of this program. ITC intends to continue the staged installation of additional LEL monitors/flammable gas detectors in the atmospheric storage tank farms across the terminal.

Facilities like ITC should have flammable gas detection systems in place that are designed and installed properly; maintained properly; and have procedures, training, testing, and drills associated with their proper operation. API STD 2610 mentions the use of vapor-detection systems in emergency shutdown systems; however, it and several of its normative references[a] do not explicitly discuss flammable gas detection systems in describing leak detection systems for terminals and tank facilities [25].[b] The CSB concludes that terminals and tank facilities that store flammable substances should develop, implement, and maintain flammable gas detection systems to alert workers to hazardous conditions and allow them to respond in a timely manner.

The CSB recommends that API update API STD 2610, *Design, Construction, Operation, Maintenance, and Inspection of Terminal and Tank Facilities*, or other appropriate products to include flammable gas detection systems within the leak detection section or where appropriate. The discussion of flammable gas and/or leak detection should address both engineering and administrative controls, including actions associated with responding to a catastrophic or emergency leak (**2019-01-I-TX-R6**).

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[a] Normative references are those documents that contain material that must be understood and used to implement a standard [74].

[b] Leak detection programs allow for the detection and prompt resolution of a release with the goal of mitigating its consequences. Applying a similar approach to terminals and tank facilities that store highly hazardous chemicals could allow each facility to establish its own leak detection strategy, methods, and performance measures. API Recommended Practice 1175, *Leak Detection – Program Management* (API RP 1175) provides guidance on developing a leak detection program for pipelines that could be referred to as a basis for developing a leak detection program at terminals and tank facilities [79]. API's recommended leak detection program includes the following components:

- Management commitment and leadership
- Risk assessment
- Selection of leak detection methods
- Performance targets, metrics, and key performance indicators
- Testing
- Procedures for recognition and response
- Alarm management
- Roles, responsibilities, and training
- Reliability and maintenance requirements for leak detection equipment
- Overall performance evaluation of the leak detection program
- Training
- Management of change
- Improvement process

4.3 REMOTELY OPERATED EMERGENCY ISOLATION VALVES

Tank 80-8 was not equipped with a remotely operated emergency isolation valve (ROEIV) to isolate the contents of the aboveground storage tank from the piping manifold in the event of a release.[a] At the time of the incident (and currently) ROEIVs were not required under applicable atmospheric storage tank standards [26, p. 7]. Regarding its corporate standards or policies on the application and use of ROEIVs, ITC informed the CSB that *"ITC installs motor operated valves on tank discharges as the tanks are taken out of service for periodic API 653."* In the case of Tank 80-8, the next API 653[b] inspection was scheduled to take place in November 2022.

Several recognized industry process safety sources recommend the use of ROEIVs on equipment containing large volumes of flammable and toxic material:

- CCPS[c] states that "[r]emote isolation of equipment containing hazardous material is necessary to mitigate a release of hazardous material when there has been loss of containment. Isolation can be accomplished with the appropriate location of remotely operated… [emergency block valves (EBVs)]. Remotely operated EBVs should be located such that major process equipment or unit operations can be isolated in the event of a loss of containment" [27].
- The *Health and Safety Executive* (HSE)[d] states that "appropriate means of isolation, which may include [Remotely Operated Shutoff Valves], should be provided between individual inventory units to limit the quantity of substance that can be released from any single failure" [28, p. 26].
- In 2020, Marsh Specialty published a risk engineering position paper on ROEIVs, stating, "Many small incidents have escalated into major losses because personnel were unable to reach, and close, manual block valves safely or quickly enough, leading to unconstrained supply of fuel to the fire" [29, p. 2].
- API STD 2610 for terminal and tank facilities recommends, "Emergency shutdown systems and procedures should be provided at all product transfer facilities. [...] The emergency shutdown system should shutdown all flow and provide a visual or audible indication to personnel in the area [...]" [25, p. 37].

A past insurance audit for the ITC Deer Park terminal conducted in October 2018 indicates that LPG tanks located in another area of the terminal were equipped with electric motor operated valves (MOVs) that were programmed to close the inlet valve and automatically shut down the associated pumps under certain scenarios. Over the years, consistent with its inspection schedule, ITC had equipped twelve of the fifteen (15) 80,000-

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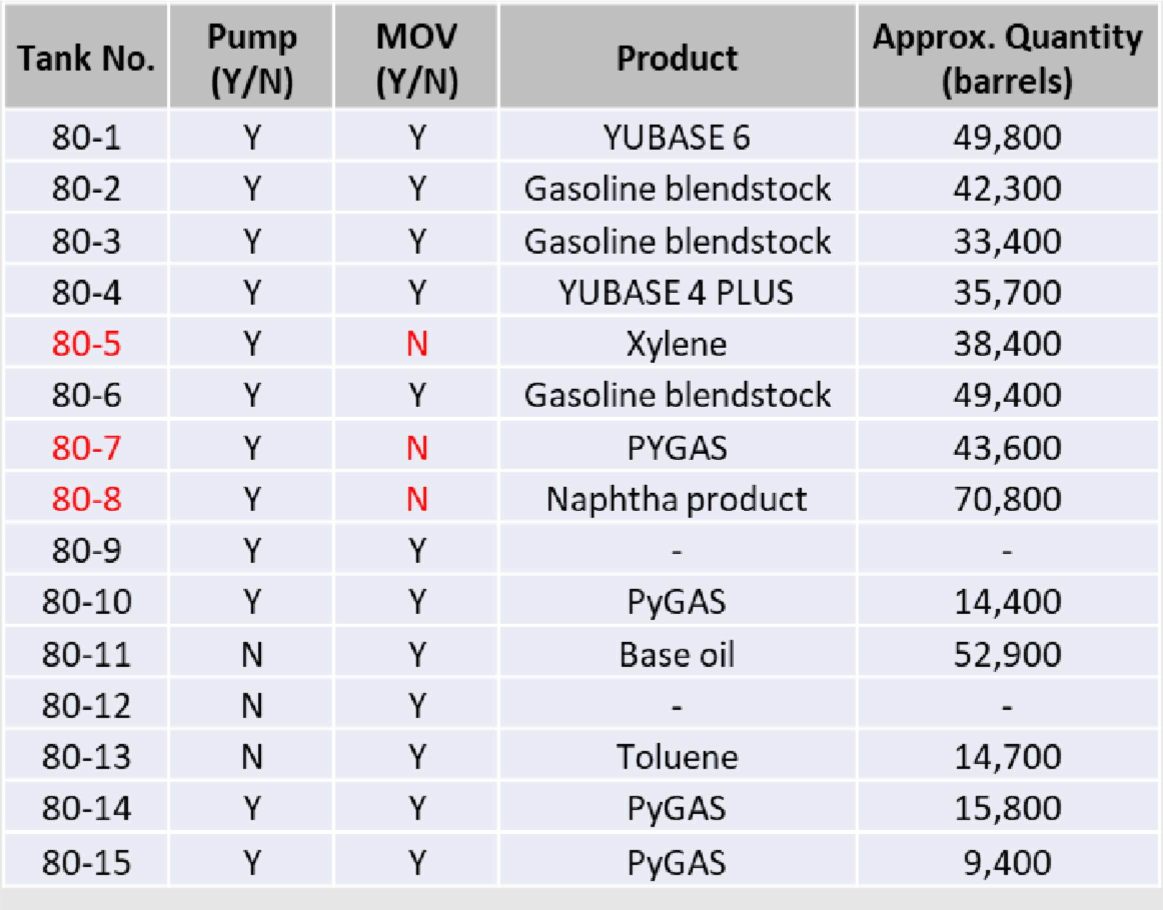
[a] An emergency or remotely operated isolation valve is often referred to as an ROEIV, an emergency isolation valve (EIV), or an emergency block valve (EBV). These types of valves are equipped with actuators and configured to be quickly and reliably operated from a safe location, such as a control room [27, p. 7].

[b] API 653 is the standard for tanks over 50 feet tall or having a diameter greater than 30 feet. The standard covers the maintenance, inspection, alteration, and repair of steel, field-erected aboveground storage tanks (ASTs) built to API STD 650 or API 12C standards. API 653 external inspections are required every five years, and API 653 internal inspections, which require the tank to be out of service, are required every 10 years. All inspections must be performed by a licensed inspector.

[c] CCPS is a not-for-profit corporate membership organization within AIChE, with over 200 members, that identifies and addresses process safety needs in the chemical, pharmaceutical, and petroleum industries. While CCPS does not establish any requirements, its publications are intended to help organizations design and implement more effective process safety management systems.

[d] The Health and Safety Executive (HSE) is Britain's national regulator for workplace health and safety.

barrel storage tanks located in the First & Second 80’s tank farm with MOVs (**Figure 29**); however, ITC did not equip these valves with fusible links,[a] programming logic, or other protective measures to help ensure that these valves would automatically close in the event of a power outage, fire, or other event (“Fail-Closed”).



Tank No.	Pump (Y/N)	MOV (Y/N)	Product	Approx. Quantity (barrels)
80-1	Y	Y	YUBASE 6	49,800
80-2	Y	Y	Gasoline blendstock	42,300
80-3	Y	Y	Gasoline blendstock	33,400
80-4	Y	Y	YUBASE 4 PLUS	35,700
80-5	Y	N	Xylene	38,400
80-6	Y	Y	Gasoline blendstock	49,400
80-7	Y	N	PYGAS	43,600
80-8	Y	N	Naphtha product	70,800
80-9	Y	Y	-	-
80-10	Y	Y	PyGAS	14,400
80-11	N	Y	Base oil	52,900
80-12	N	Y	-	-
80-13	N	Y	Toluene	14,700
80-14	Y	Y	PyGAS	15,800
80-15	Y	Y	PyGAS	9,400

Figure 29. List of aboveground atmospheric storage tanks, associated equipment, and products contained in First & Second 80’s tank farm. (Credit: CSB)

On the day of the incident, a single pump seal failure escalated to a catastrophic incident. When the flammable butane-enriched naphtha ignited, the resulting fire caused a power outage to the controls communication system almost immediately after ignition, which rendered all the First & Second 80’s tank farm MOVs inoperable and incapable of providing remote isolation. As a result, when the Tank 80-8 circulation pump failed, the large volume of butane-enriched naphtha product contained in the 80,000-barrel atmospheric storage tank could not be remotely or automatically isolated. Additionally, since the flames immediately engulfed the entire area, neither ITC personnel nor emergency responders were able to physically access the supply and return valves on the tank to manually close them and isolate the tank. As a result, the butane-enriched naphtha product continued to release from Tank 80-8, via the failed pump, and fueled the fire that continued to intensify around Tank 80-8 and its piping manifold. The CSB concludes that had Tank 80-8 been equipped with a remotely operated emergency isolation valve (ROEIV), the butane-enriched naphtha product release could have been secured

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[a] Fusible link valves are shut-off valves that close automatically in the presence of fire. The fusible link is a heat-sensitive device that releases a spring pack when exposed to high temperature, allowing the valve to close [73].

without the need for personnel to enter the tank farm, allowing emergency responders to extinguish the initial fire earlier in the response.

As the Tank 80-8 fire intensified, flames from the fire spread across the common containment area to adjacent tank piping manifolds in the First & Second 80's tank farm. The flames eventually compromised the equipment, causing breaches in piping that allowed the hydrocarbon and petrochemical products contained in the storage tanks to release into the common containment area. Since none of the storage tanks were equipped with ROEIVs and the MOVs that were present were rendered inoperable, there was no opportunity to isolate any of the impacted tanks. As a result, the hydrocarbon and petrochemical products stored in the impacted tanks continued to release, further fueling and expanding the fire throughout the tank farm. Consequently, the fire that originated in the Tank 80-8 piping manifold burned for nearly three days and involved twelve (12) of the fifteen (15) 80,000-barrel capacity atmospheric storage tanks commonly contained in the First & Second 80's tank farm. The CSB concludes that had remotely operated emergency isolation valves (ROEIVs) configured to "Fail-Closed" been installed on Tank 80-8 and the other 14 tanks in the First & Second 80's tank farm, the tanks could have been secured without the need for personnel to enter the tank farm after power was lost to all motor operated valves (MOVs), and the quantity of the materials released could have been reduced. Thus, the CSB recommends that ITC install remotely operated emergency isolation valves configured to "Fail-Closed" for all atmospheric storage tanks that contain highly hazardous chemicals or liquids with a flammability rating of NFPA-3 or higher at the ITC Deer Park terminal (**2019-01-I-TX-R4**).

While ROEIVs were not as common when the First & Second 80's tank farm was originally constructed, they could have been incorporated by way of equipment upgrades or modifications. The primary drivers for identifying the need for this type of equipment would have been through implementation of hazard assessments, such as those required by the PSM process standard and the RMP rule, insurance company audits, and/or corporate risk evaluations results. As previously discussed, ITC took the position that the atmospheric storage tanks in the First & Second 80's tank farm were not subject to OSHA's PSM standard or EPA's RMP rule (discussed further in Section 4.5).[a] Moreover, the insurance audits of the ITC Deer Park terminal did not identify any concerns with

KEY LESSON

Companies that handle large volumes of flammable or highly hazardous substances should assess their capability to remotely isolate these substances in the event of a loss of containment. Aboveground atmospheric storage tanks that contain large volumes of these substances should be equipped with remotely operated emergency isolative valves (ROEIVs) so that releases can be mitigated quickly and remotely from a safe location. The ROEIVs should be equipped with fusible links or configured to automatically close in the event of a power outage or other event ("Fail-Closed").

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[a] As discussed in detail in Section 4.5.1.2, following the March 2019 incident, OSHA cited the ITC Deer Park terminal for violation of the PSM standard. OSHA and ITC eventually entered into a settlement agreement, whereby ITC paid the penalties for the alleged violations and agreed to conduct an enhanced abatement at the ITC Deer Park terminal. However, in the settlement ITC did not concede its belief that Tank 80-8 was exempt from coverage under the OSHA PSM standard, and the PSM compliance related language was removed from the citations.

the absence of ROEIVs in the tank farm. NFPA 30, *Flammable and Combustible Liquids Code* (NFPA 30)[a] [30] and API Recommended Practice 2021, *Management of Atmospheric Storage Tank Fires* (API RP 2021)[b] [31] do not dictate the use of specific technologies, such as ROEIVs, but do include performance and/or functional requirements that can be achieved through their use.

Since the time of the incident, ITC informed the CSB that they initiated a phased program to install independent, fire-safe, emergency shutdown valves at all product storage tanks across the facility. According to the information provided, the emergency shutdown valves will be pneumatically operated, with both remote and local controls, and include fusible links for automatic shutdown during a fire event. ITC indicated that the enhancement also includes upgraded fire-rated gaskets with higher temperature tolerances. To date, ITC has completed installation of 98 emergency shutdown valves at the ITC Deer Park terminal. The company indicated that ongoing implementation of this program will be conducted in conjunction with ITC's existing program for conducting tank enhancements when tanks are taken out of service for inspection or other reasons, with tanks containing products with higher NFPA flammability ratings being addressed on a more accelerated basis.

The ITC Deer Park terminal incident demonstrates the extent and severity of what can happen when large-volume storage tanks, situated in a common containment area, cannot be remotely isolated in the event of an unintended release and fire. The CSB investigated two other incidents in 2019 in which lack of ROEIVs contributed to the severity of the consequences:

- On June 21, 2019, a pipe elbow in the Philadelphia Energy Solutions (PES) hydrofluoric acid (HF) alkylation unit ruptured. A large vapor cloud—composed of about 95% propane, 2.5% HF, and 2.5% other hydrocarbons—engulfed part of the unit. The vapor cloud ignited two minutes after the release began, causing a large fire. The CSB investigated this incident and found that the release location could not be isolated from the rest of the process [32].
- On November 27, 2019, a series of explosions occurred at the TPC Group (TPC) Port Neches Operations (PNO) facility, located in Port Neches, Texas, after highly flammable butadiene was released from the process unit. The explosions caused a process tower to propel through the air and land within the facility, other process towers to fall within the unit, extensive facility damage, and fires that burned for more than a month within the facility. The butadiene unit was destroyed, forcing the facility to cease butadiene production operations indefinitely. The CSB investigated this incident and found that the TPC PNO butadiene process was not equipped with ROEIVs designed to mitigate process releases remotely from a safe location. As a result, the release location could not be isolated from the rest of the process [34].

The CSB intends to conduct further analyses of incidents involving lack of remote isolation capability to determine the appropriate course(s) of action to recommend to industry groups and regulatory agencies.

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[a] NFPA 30, *Flammable and Combustible Liquids Code* provides safeguards to reduce the hazards associated with the storage, handling, and use of flammable and combustible liquids, including tank farm design, construction, and spacing requirements.

[b] API RP 2021, *Management of Atmospheric Storage Tank Fires* provides experience-based information to enhance the understanding of fires in atmospheric storage tanks containing flammable and combustible materials. It provides information to assist management and fire suppression personnel to manage the needs associated with safely fighting fire in aboveground storage tanks.

4.4 TANK FARM DESIGN

Tank 80-8 was situated in the center of the First & Second 80's tank farm, which consisted of fifteen (15) 110-foot diameter, 80,000-barrel capacity aboveground atmospheric storage tanks located within a common containment area that measured approximately 732 feet in length by 449 feet in width and was surrounded by a roughly 4-foot tall concrete containment wall.

NFPA 30 provides safeguards to reduce the hazards associated with the storage, handling, and use of flammable and combustible liquids, including tank farm design, construction, and spacing requirements.[a] At the time of construction of the First & Second 80's tank farm, the 1973 version of NFPA 30 would have been in effect [10].[b]

The CSB contracted a third-party fire protection specialist, Jensen-Hughes, to evaluate and provide perspective on the tank farm fire (Appendix D). The attached Jensen-Hughes report provides additional details of ITC Deer Park's tank farm design. In addition, the CSB contracted a structural engineering firm, Atlas Engineering, to evaluate the containment wall failure (Appendix E).

4.4.1 TANK SPACING

In reviewing ITC's First & Second 80's tank farm spacing, the Jensen-Hughes report concluded that the tank farm spacing was designed in accordance with most of the NFPA 30 requirements for floating roof aboveground atmospheric tanks in place at the time the tank farm was constructed, including:

- Required minimum distance from property line and nearest side of public way or building (Section 2110) [9, p. 17] (Appendix D, pg. 13); and
- Required minimum shell-to-shell spacing between any two adjacent tanks (i.e., not less than one-sixth their diameters) (Section 2122) [9, p. 21] (Appendix D, pg. 13).

In addition to the above minimum tank spacing requirements, Section 2125 of the 1973 version of NFPA 30 states:

> When tanks are in a diked area containing Class I or Class II liquids,[c] or in the drainage path of Class I or Class II liquids, and are compacted in three or more rows or in an irregular pattern, greater spacing or other means may be required by the authority having jurisdiction to make inside tanks accessible for fire fighting purposes [9, p. 22].

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[a] https://www.nfpa.org/News-and-Research/Data-research-and-tools/Hazardous-Materials/The-fire-risk-of-Intermediate-Bulk-Containers/About-NFPA-30.

[b] The 1973 edition of NFPA 30 covers tank storage requirements under Chapter II.

[c] Flammable liquids are classified by NFPA as Class I liquids. Class I liquids are further subdivided into three classes: IA, IB, and IC. These liquids have flash points below 100°F or less. Combustible liquids are classified by NFPA as Class II and Class III liquids. Class II liquids have flash point at or above 100°F and below 140°F, while Class III combustible liquids have a flash point at or above 140°F and below 200°F. The butane-enriched naphtha product in Tank 80-8 was a Class I liquid.

The 2018 edition of NFPA's *Flammable and Combustible Liquids Code Handbook* (2018 NFPA 30 Handbook) notes that tank spacing for larger tanks is an arbitrary fraction of tank diameter, sufficient to permit an orderly and safe arrangement for pipelines and to prevent the spread of fire from one tank to another. The handbook also notes, "Spacing alone is not a safeguard against fire spread from spilled liquid," and directs the user to Section 22.11 for the control of spills (Note to 22.4.2.1*) [34].

When the tank farm was constructed, ITC spaced the 15 tanks in three rows of five roughly 36 feet from one another, in accordance with the minimum required shell-to-shell spacing distance specified in NFPA 30. The company later installed four fixed fire monitors in the interior of the tank farm in 2018. According to ITC, these interior fire monitors (in conjunction with the fire monitors mounted on the periphery of the tank farm) were intended to allow the company to direct at least one fire monitor to any tank manifold within the tank farm.

In order to understand the mechanism by which the fire spread, Jensen-Hughes modeled the combined pool fire and tank fire and examined its thermal outputs. The detailed fire modeling results indicated that flames issuing from the roofline tank vents did not provide enough heat to cause the fire to spread to adjacent tanks; however, the synergistic effects of the tank fire and ground-level liquid pool fire were sufficient to lead to ignition of adjoining tanks. According to the expert's report:

> [T]he results of the study indicate that the coupled impact of a tank fire and a liquid pool fire may need to be considered in evaluating the minimum safe separation distance of future installations and to evaluate existing installations, particularly older installations that predate the availability of safety features or equipment that aid in mitigating such conditions. Although a relatively limited pool fire was examined in this analysis, the combined impact of the pool and vent fires significantly raised the radiant exposure to adjoining tanks. Were the pool fire expanded in the model, as it did during the ITC Deer Park fire, igniting the contents of adjacent tanks from radiant heat exposure would be more likely (Appendix D, pg. 22).

While NFPA 30 defines minimum requirements for tank farm design, additional industry discussions were taking place regarding tank farm fire safety around the time of construction of the First & Second 80's tank farm. For example, in July 1974, the Oil Insurance Association (OIA)[a] published *Loss Control Bulletin No. 400-1*, which discusses losses involving atmospheric storage tanks resulting from tank fires [35]. According to this document, the severity of tank fires is most affected by "spacing, common containment (diking), piping within containment areas, and inadequate foam and fire water supplies," all of which can be "controlled and reduced by good fire prevention practices." Accordingly, the document contains a series of comments and recommendations for tank spacing, including:

> Generous spacing between individual tanks and between tank fields and process areas is a must. Radiant heat has damaged adjacent exposed tanks over a tank diameter away even when there has been no ignition of the second tank. Heavy water streams may provide somewhat of an alternative by protecting exposed

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[a] The OIA merged with Factory Insurance Association in 1975 and is now called Industrial Risk Insurers. It is a consortium of major stock property and casualty insurers formed to write large, highly protected risks and to provide fire laboratory facilities and engineering services.

tanks, but their availability and continuity cannot be relied upon with certainty [35, p. 45].

KEY LESSON

NFPA 30 provides safeguards to reduce the hazards associated with the storage, handling, and use of flammable and combustible liquids, including tank farm design and spacing requirements. While NFPA 30 defines minimum requirements for tank farm design and spacing, other voluntary industry guidance documents including FM Global Loss Prevention Data Sheet (FM LPDS) 7-88, *Outdoor Ignitable Liquid Storage Tanks*; and API RP 2021, *Management of Atmospheric Tank Fires*; and API STD 2610, *Design, Construction, Operation, Maintenance and Inspection of Terminals and Tank Facilities* provide more robust tank farm design criteria.

The *Loss Control Bulletin No. 400-1*, recommends storage tanks with capacities greater than 50,000 barrels to be spaced one and a half times the tank diameter apart. In the case of the First & Second 80's tank farm, this would have meant that the 15 storage tanks would have been spaced 165 feet apart, according to the recommendation. Because these and other general industry guidance documents do not contain strict, enforceable requirements such as those in NFPA 30; companies typically evaluate these considerations for their own facilities as applicable. For example, a property insurance survey conducted at the ITC Deer Park terminal on April 10, 2017, noted that tank spacing in the First & Second 80's tank farm was "tight," but did not identify any discrete concerns or recommendations related to tank spacing.

During the March 2019 incident, emergency responders were unable to access or activate the fixed fire monitor that was designed to reach Tank 80-8, as it was engulfed in flames from the fire in the Tank 80-8 piping manifold. Additionally, the positions of other fixed fire monitors inside the tank farm did not allow for them to be aimed directly at the fire engulfing the Tank 80-8 piping manifold, as they were not designed to reach that area. As a result, the fire spread to an adjacent tank. The fixed fire monitors located inside the tank farm may have been added to the First & Second 80's tank farm to address the compacted tank spacing concerns identified in NFPA 30; however, they were ineffective during the response to this event. The CSB concludes that although the First & Second 80's tank farm was designed in accordance with applicable NFPA 30 tank farm spacing requirements in place at the time the tank farm was constructed, the NFPA 30 recommendation for additional spacing for compacted tank farm layouts was not included in the design. This design, which allowed for reliance on administrative controls and emergency response, allowed the Tank 80-8 fire to spread and involve additional tanks in the tank farm.

The CSB recommends that ITC conduct an evaluation of the design of all new and existing tank farms at the ITC Deer Park terminal. The evaluation should identify additional engineering controls needed to address minimal tank spacing (**2019-01-I-TX-R5**).

4.4.2 SUBDIVISIONS

In reviewing ITC's First & Second 80's tank farm containment area, the Jensen-Hughes report concluded that the containment area was designed in accordance with the following NFPA 30 requirement for floating roof aboveground atmospheric tanks in place at the time the tank farm was constructed:

- Volumetric capacity of the diked area should be sized to accommodate the greatest amount of liquid that can be released from the largest tank within the diked area, with consideration of any other tanks within the containment accounted for (Section 2173(a)) [9, p. 29] (Appendix D, pg. 14).

In addition to this containment requirement, Section 2173(g) of the 1973 version of NFPA 30 required[a] that each diked area containing two or more tanks be subdivided by drainage channels or at least by intermediate curbs in order to prevent spills from endangering adjacent tanks within the diked area. Section 2173(g)(2) of NFPA 30 states:

> When storing normally stable flammable or combustible liquids in tanks not covered in sub-paragraph (1), one sub-division for each tank in excess of 100,000 gallons (2,500 bbls) and one sub-division for each group of tanks (no tank exceeding 100,000 gallons capacity) having an aggregate capacity not exceeding 150,000 gallons (3,570 bbls) [9, p. 30].

Section 2173(g)(4) of NFPA 30 further specifies that:

> The drainage channels or intermediate curbs shall be located between tanks so as to take full advantage of the available space with due regard for the individual tank capacities. Intermediate curbs, where used, shall be not less than 18 inches in height [9, p. 30].

With regards to the First & Second 80's tank farm subdivisions, the Jensen-Hughes report states:

> The drainage as provided segregates the tank farm into groups of three tanks each, while Section 2173(g)(2) would have required the drainage to be provided such that each tank was separated from adjoining tanks. Section 2173 allows for the use of intermediate containment walls to either replace drainage or augment drainage, however no intermediate containment walls are provided. The sloping and draining across the entire tank area, evidenced by a general slope from the north to south direction and additional drains at the south side of the farm, may have been provided to offset the lack of inlets between tanks. In theory, the slope would move any spilled liquids away from the immediate tank of concern and transfer the liquids to the drainage system at the south side. As an alternative approach, the provided condition doesn't satisfy the intent of the requirements in Section 2713(g)(2) (Appendix D, pg. 14).

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[a] In this section of the code, NFPA 30 states that these requirements apply to drainage and diked areas for aboveground tanks "except that in particular installations these provisions may be waived or altered at the discretion of the authority having jurisdiction when the tanks under consideration do not constitute a hazard to adjoining property" [10, p. 28]. The CSB could not determine whether the Harris County Fire Marshal waived this requirement for the First & Second 80's tank farm at the time it was constructed.

The 1974 OIA *Loss Control Bulletin No. 400-1* had made the following observations about tank farm subdivisions:

> Common diking (more than one tank within one dike[a] area) has been the greatest single factor in determining the size of a loss wherever it has been involved. It has usually proved almost impossible to prevent the spread of fire to other tanks when they are not separated by dikes. Further, when more than one tank is burning, extinguishment of any of them is vastly more difficult and total destruction usually results. Where full separating dikes are impossible, careful consideration should be given to diversion dikes and grading to drain away from other tanks [36].

ITC had “small concrete containment area[s]” immediately adjacent to the majority of the tanks at its facility, including Tank 80-8 (**Figure 30**). ITC’s Spill Prevention Control and Countermeasure Plan (SPCC) stated that these concrete containment areas were designed to provide local containment and drainage capabilities for pumps and valves associated with the tanks: “Leaks, drips, etc. that originate at the pumps/valves are contained and immediately drained to the wastewater treatment system via the chemical drain system.” This was the only containment area that separated Tank 80-8 spills from adjacent tanks. On the day of the incident, the butane-enriched naphtha product released from Tank 80-8 overflowed this small containment area and entered the common containment area of the tank farm.

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[a] NFPA defines a dike as a structure used to establish an impounding area or containment [71].

Figure 30. Small concrete containment area around the Tank 80-8 circulation pump. (Credit: CSB)

The CSB concludes that ITC's First & Second 80's tank farm was not subdivided as was required by NFPA 30. Although the subdivisions of the diking required by NFPA 30 likely would have been insufficient to hold the full contents of Tank 80-8, additional subdivisions could have slowed the spread of the butane-enriched naphtha product and allowed responders the opportunity to access and activate the fixed fire monitors located within the containment area to fight the fire surrounding the Tank 80-8 piping manifold before it spread to adjacent tanks.

The First & Second 80's tank farm was not the only tank farm at the ITC Deer Park terminal that contained this type of arrangement. Among others at the terminal, the Third 80's tank farm, located adjacent to the First & Second 80's tank farm (see **Figure 3**), contained 12 large-capacity atmospheric storage tanks and their associated piping manifolds/equipment, spaced similarly, within a common containment area. As a result, the CSB recommends that ITC conduct an evaluation of the design of all new and existing tank farms at the ITC Deer Park terminal. The evaluation should identify additional engineering controls needed to address subdivisions between tanks (**2019-01-I-TX-R5**).

4.4.3 PROCESS EQUIPMENT WITHIN SECONDARY CONTAINMENT

The Tank 80-8 circulation pump, and 11 other pumps were located inside the secondary containment area in the First & Second 80's tank farm. NFPA 30 has permitted and still permits placement of process equipment within tank farms. Starting in 2012, NFPA began to require closer examination of placement of process equipment within tank farms; however, NFPA 30 does not retroactively apply. The 2012 edition states:

> **22.12.3* Location of Equipment.** If located in a remote impoundment area, a diked area, or a spillway draining to a remote impoundment area, process equipment, pumps, instrumentation, and electrical utilization equipment shall be located or protected so that a fire involving such equipment does not constitute an exposure hazard to the tank or tanks in the same area for a period of time consistent with emergency response capabilities. **(2012 – 22.12.3*)**
>
> **A.22.12.3** Methods of preventing an exposure hazard include intermediate diking, drainage, or fire protection features such as water spray systems, monitors, or fire-resistive coatings. High integrity pumps or equipment also constitute a method of limiting exposure hazards. **(2012 – A.22.12.3)** [36]

Other industry guidance acknowledged the increased risk of locating pumps inside tank farms prior to the 2012 NFPA 30 update. For example, OIA's 1974 *Loss Control Bulletin No. 400-1* states: "Pumps should be installed outside of dikes, not only because they are sources of ignition but also because they may be vital for the transfer of product to a safe tank." A more recent industry guidance document, API STD 2610, *Design, Construction, Operation, Maintenance, and Inspection of Terminal & Tank Facilities*, first published in 1994, states: "pumps inside secondary containment are considered ignition sources due to the possibility of mechanical seal failures and should be located outside the secondary containment area." It adds that "if pumps are located within containment areas, sound risk management principles should be used to mitigate the risks of locating the pump inside the secondary containment area" [26].

ITC did implement some engineering controls to mitigate the risks of operating the Tank 80-8 circulation pump inside the secondary containment area. As mentioned previously, the circulation pump was located inside a small concrete containment area designed to capture and direct "leaks, drips, etc." from the pump into the chemical drain system. In addition, in 2018, ITC added four new fire monitors to the interior area of the tank farm to allow the company to direct at least one fire monitor to any tank manifold within the tank farm.

ITC had an opportunity to revisit its engineering controls around the Tank 80-8 circulation pump in 2014, when the company performed a voluntary PHA to evaluate risks associated with adding butane injection capability to the tank. The team recognized that one of the hazards involved with product storage and circulation was potential loss of containment, the consequences of which were product release, fire, explosion, exposures, injuries, and fatalities. The project team recommended that ITC "consider projects for LEL meters/deluge at pumps"; however, ITC ultimately decided not to install an LEL detector or deluge system at the Tank 80-8 circulation pump. On the day of the March 2019 incident, the one monitor that was designed to reach the Tank 80-8 manifold required manual activation and was already engulfed in the fire when emergency responders arrived. The CSB concludes that had ITC implemented additional engineering safeguards, such as flammable gas detection systems and remotely operated emergency isolation valves (ROEIVs), to mitigate the risks of operating the Tank 80-8 circulation pump inside the secondary containment area, the spread of the initial fire could have been slowed or prevented.

The CSB recommends that ITC conduct an evaluation of the design of all new and existing tank farms at the ITC Deer Park terminal. The evaluation should identify additional engineering controls needed to address placement of process equipment in containment areas (**2019-01-I-TX-R5**).

4.4.4 DRAINAGE

There were two drainage systems in place within the First & Second 80's tank farm: a chemical drain system and stormwater drain system. Materials collected in the chemical drain system were routed via underground piping to the terminal's wastewater treatment system. The stormwater drainage system was responsible for collecting stormwater from the First & Second 80's tank farm and directing it through pipes and control structures to an adjacent drainage ditch through a discharge location near the northwest corner of the tank farm (**Figure 31**). A Harris County drainage ditch was located just outside of the containment wall and inside of Tidal Road on the north side of the First & Second 80's tank farm.

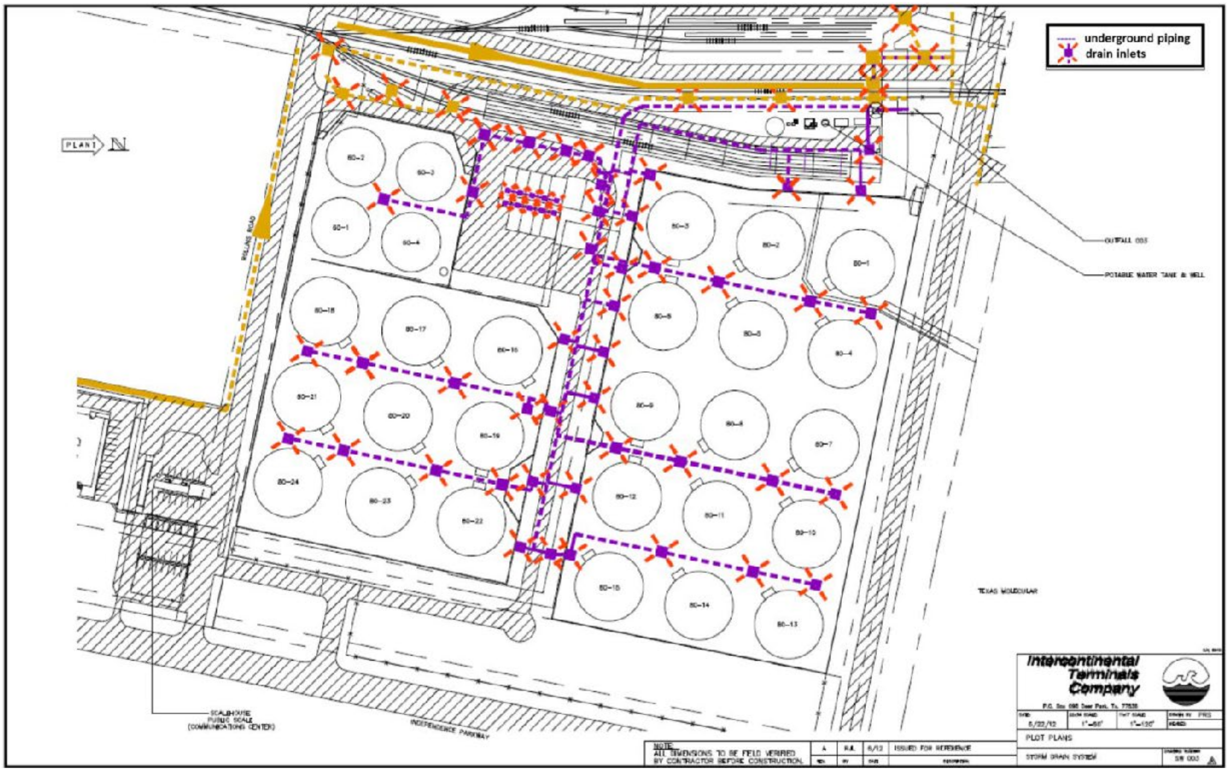

Figure 31. Plot plan of First & Second 80's tank farm stormwater drain system. (Credit: ITC)

Although the First & Second 80's tank farm was designed largely in accordance with NFPA 30 (1973 edition), a convergence of several issues related to liquid accumulation resulted in complications during the emergency response, including:

- The stormwater drain system in the tank farm was unable to quickly remove the quantity of released materials and firewater from the containment area;

- The stormwater drains were generally positioned along the same pathway as the transverse piping that ran north to south in between the tanks;

- The tank farm was graded to facilitate drainage to stormwater catch basins on the south side of the tank farm; and

- The containment wall failed, allowing the mixture of hydrocarbon products, firefighting foam, and contaminated water to eventually enter the Houston Ship Channel.

The stormwater drain system allowed the water, released materials, and firefighting foam to accumulate in the containment area while emergency responders were fighting the fire. The tank farm grading also provided a means for the fire to spread across the tank farm. The water and released materials flowed toward the transverse piping and piping manifolds and then south, which would have caused a "running fire" (i.e., one that tracked with the spill) that exposed other tanks and their respective piping manifolds prior to entering the drainage system. Since both naphtha and xylene are lighter than water,[a] the initially released flammable products floated on top of the water in the containment area, ignited, and caused several small fires to burn on the water surface where gaps in the foam existed. The movement of the fire toward the south prevented emergency responders from accessing the firewater system valves and foam connections located along the containment wall on the south side of the tank farm. It also prevented emergency responders from being able to position personnel at the monitor nozzles or employ other fire apparatus or equipment in this area.

Burning liquid on the ground or floating on the water during the initial and subsequent releases likely contributed to thermal exposure to the tanks as the burning liquid moved toward and then passed the tanks on its way toward drains. This movement continued as the stormwater drainage system became overwhelmed by the volume of materials, which partially explains the fire spread. This also helps explain why fire damage on the south side of the tank farm was more severe than on the north side.

The CSB contracted a structural engineering firm, Atlas Engineering, to evaluate the containment wall failure that occurred several days after the initial fire began (Appendix E). Although Atlas arrived at the ITC Deer Park terminal two years after the incident, in 2021, after remediation measures had already been performed, they were able to observe that "the wall was of adequate height to meet NFPA requirements for capacity and total height and contained waterstop detailing in an effort to maintain a water-tight wall" (Appendix E, pg. 24). In addition, the First & Second 80's tank farm was designed to retain at least 100% of the largest tank within the tank farm in line with NFPA 30 requirements. Regarding its tank farm containment walls, ITC's Spill Prevention, Control, and Countermeasure (SPCC) plan noted:

> Based on good engineering practice and site-specific factors, these containment/diversionary systems, including walls and floors, are capable of containing and are constructed to be sufficiently impervious to contain a discharge from one of the bulk oil storage *containers* until cleanup can occur; thereby minimizing the potential for a harmful discharge of oil into or upon navigable water of the United States.

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[a] Xylene has a specific gravity of 0.87, compared with that of water, which is 1.0.

With no design documents available, Atlas could not evaluate the containment wall's original design basis or potential changes to the containment wall since its original design; however, more than one bulk storage tank was compromised during the March 17, 2019, incident, and the containment area was filled with hydrocarbon products, firefighting foam, and contaminated water for days. Based on drone footage from the incident, Atlas observed:

> The containment wall primarily displaced laterally [...] due to excessive lateral soil and hydrostatic pressures [...]. [...] With potential for as much as 4-feet of fire suppression water retained in the containment wall for days, this possibly led to saturation of the soils and increased lateral earth pressures against the containment wall (Appendix E, pg. 26).

The CSB concludes that the accumulation of hydrocarbon products, firefighting foam, and contaminated water within the First & Second 80's tank farm containment area contributed to the fire spreading to additional tanks in the common containment area. The accumulation likely also contributed to the containment wall failure, which allowed a mixture of hydrocarbon products, firefighting foam, and contaminated water to be released into the local waterways.

Section 9.2.3 of API STD 2610 addresses drainage of rainwater in tank farms. According to the document, unless other provisions are made for drainage, the floor of the diked area shall be graded to at least 1% for every 50 feet away from the tank(s) or to the dike base, whichever is less [25]. Additionally, the document states:

> The sloped area shall be directed toward one or more drain openings or retention areas. Major paths of drainage should be routed, or internal intermediate diking shall be provided, so that piping, equipment, tanks, or vessels will not be seriously exposed should flammable or combustible liquid in the drainage ditch ignite [25, p. 25].

API STD 2610 was not published until 1994, and thus did not exist at the time that the First & Second 80's tank farm was constructed; however, the recommendations contained in API STD 2610 can be considered while evaluating future recommendations related to the design of ITC's tank farms' drainage systems. The CSB recommends that ITC conduct an evaluation of the design of all new and existing tank farms at the ITC Deer Park terminal. The evaluation should assess the adequacy of the containment wall and drainage system designs, accounting for the impact of firefighting activities, including the application of firewater and foam on these systems (**2019-01-I-TX-R5**).

4.5 PSM AND RMP APPLICABILITY

4.5.1 OSHA PROCESS SAFETY MANAGEMENT (PSM) STANDARD

OSHA promulgated the *Process Safety Management of Highly Hazardous Chemicals* standard (29 C.F.R. § 1910.119), or PSM standard, on February 24, 1992,[a] following several significant incidents involving the

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[a] The PSM standard became effective on May 26, 1992.

accidental release of highly hazardous chemicals[a] that resulted in worker injuries and fatalities [37]. The PSM standard, comprised of 14 key elements, requires facilities to develop and implement a process safety management program for covered processes[b] involving highly hazardous chemicals that integrates technologies, procedures, and management practices to help ensure safe and healthful workplaces. The main objective of the PSM standard is to prevent or minimize the consequences of catastrophic releases of toxic, reactive, flammable, or explosive chemicals, as these releases may result in toxic, fire, or explosion hazards [38].[c]

According to 29 C.F.R. §1910.119(a)(1), the requirements of the PSM standard are applicable to any process that involves highly hazardous chemicals, at or above the specified threshold quantities. In terms of applicability, OSHA defines a process as "any activity involving a highly hazardous chemical including any use, storage, manufacturing, handling, or on-site movement of such chemicals, or combination of these activities" [39]. OSHA provides a *List of Highly Hazardous Chemicals, Toxics and Reactives* in Appendix A[d] of the standard that includes the chemical names and threshold quantities of hazardous chemicals that are subject to the standard. In addition to processes involving the chemicals included on this list, the PSM standard is also applicable to any process that involves any Category 1 flammable gas or a flammable liquid with a flash point below 100°F, in quantities of 10,000 pounds or more, on-site in one location, with two exceptions [39]. The first exception is for hydrocarbon fuels used solely for workplace consumption as a fuel, and the second exception is for flammable liquids stored in atmospheric tanks and kept below their normal boiling point without chilling or refrigeration [39]. The second exception is commonly referred to in industry as the "flammable liquid atmospheric storage tank exemption."

4.5.1.1 PSM Standard Applicability at ITC Deer Park Terminal

ITC applied OSHA PSM standard requirements to covered processes and storage tanks containing highly hazardous chemicals at the ITC Deer Park terminal, which did not include Tank 80-8 and the other atmospheric storage tanks in the First & Second 80's tank farm. The Deer Park terminal housed 242 fixed storage tanks, ranging in size from 8,000- to 160,000-barrel capacities, at the time of the incident. The tanks were used to store various petrochemical liquids and gases, fuel and bunker oils, and distillates. Specifically, ITC determined that storage tanks containing butadiene, isoprene, LPG, and vinyl acetate monomer were covered processes under the PSM standard. ITC took the position that the remainder of storage tank operations at the terminal, including Tank 80-8 and the other tanks located in the First & Second 80's tank farm, were not PSM-covered processes. According to ITC, the storage of butane-enriched naphtha product in Tank 80-8 was exempt from PSM coverage based on the atmospheric storage tank exemption.

ITC informed CSB investigators that the company assesses applicability of the OSHA PSM standard for all new processes and products at the terminal and makes a determination of applicability prior to the introduction of the new process or product at the terminal. When the company receives a customer request for a new process or product, it is initially directed to the Safety, Health, Environmental & Security (SHES) Department for

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[a] The OSHA PSM standard defines "highly hazardous chemical" as "a substance possessing toxic, reactive, flammable, or explosive properties…" 29 C.F.R. § 1910.119(b).

[b] The PSM standard defines a "process" as "any activity involving a highly hazardous chemical including any use, storage, manufacturing, handling, or the on-site movement of such chemicals, or combination of these activities…" 29 C.F.R. § 1910.119(b).

[c] 29 C.F.R. § 1910.119. *Purpose.*

[d] 29 C.F.R. § 1910.119. Appendix A.

evaluation of regulatory and permitting applicability, which includes the PSM standard. The customer request is then distributed to other relevant departments, including the Operational Excellence group, for further evaluation. Upon completion of review, ITC either approves or denies the new request.

According to the process outlined above, when the customer request for adding butane injection capability to Tank 80-8 was received in 2014, the request was directed to the SHES and Operational Excellence groups for evaluation of PSM standard applicability. The VP SHES told investigators that he was involved in the initial review of the customer request, as was the Manager of Operational Excellence, and they determined that the request was not subject to coverage under the PSM standard since flammable liquid storage in an atmospheric tank was exempt from coverage. He told investigators that adding butane to the naphtha stored in Tank 80-8 did not change the product stored in the tank; it was still naphtha, which was not subject to PSM standard requirements.

4.5.1.2 OSHA Citations for PSM Standard Violations

Following the March 17, 2019, incident at the ITC Deer Park terminal, OSHA launched an inspection of the facility. As a result of the inspection, OSHA issued four citations to ITC with a proposed penalty of $53,040 [40]. The citation included four serious violations of the OSHA PSM standard. These violations are listed below:

- "The employer failed to document that it complied with Recognized and Generally Accepted Good Engineering Practices (RAGAGEP) such as, but not limited to NFPA 11 "Low, medium, and high-expansion foam systems" and NFPA 16 "Standard for the installation of foam water sprinkler and foam-water spray systems". The employer failed to ensure the foam generating equipment such as the foam-concentrate tank and pump were constructed to resist or located so that they were protected against exposure to fire.
- In the 2nd 80s tank farm, the employer failed to implement written procedures, including those outlined in the ITC Mechanical Integrity Program, to maintain the ongoing fitness for service of Tank 80-8 injection/recirculation piping and components. This condition exposed employees to fire hazards.
- The employer failed to perform inspection and test in accordance with Recognized and Generally Accepted Good Engineering Practices (RAGAGEP), such as but not limited to API 570 "Piping Inspection Code" and API 574 "Inspection Practices for Piping System Components". The employer failed to perform inspection and tests on Tank 80-8 cargo pump discharge circulation piping and injection point process piping.
- The employer failed to correct deficiencies on process equipment, when process piping that was below its minimum required thickness was used to inject and mix Butane with Naphtha in order to raise the octane levels in Tank 80-8."

ITC contested these citations, and a settlement agreement was reached on September 15, 2020, that included amendments to each of the four violations [42]. ITC did not admit to any violations of the "Occupational Safety and Health Act or regulations or standards promulgated there under" as part of the settlement agreement. The parties also agreed that any amendments to these citations do not affect the Secretary's interpretation of the originally cited standards, compliance with the standards, or application of the standards. The revised citations are listed below:

- "The employer failed to ensure the foam generating equipment such as the foam-concentrate tank and pump were constructed to resist or located so that they were protected against exposure to fire.
- The employer failed to implement written procedures to maintain the ongoing fitness for service of Tank 80-8 injection/recirculation piping and components.
- The employer failed to perform inspections and tests on Tank 80-8 cargo pump discharge circulation piping and injection point process piping.
- The employer failed to detect deficiencies on process equipment."

ITC also agreed to conduct an enhanced abatement at its Deer Park facility and to comply with all applicable abatement verification provisions 29 C.F.R. §1903.19 as part of the settlement agreement [42]. The terms of the enhanced abatement, as described in Exhibit A of the settlement agreement, included a series of exercises to be completed by the company for 180 existing storage tanks ("covered tanks") and their associated piping and equipment ("covered tank systems") at the Deer Park facility.[a]

The exercises involved compiling safety information for each of the covered tanks and covered tank systems; performing hazard reviews for the covered tanks to address the hazards associated with loading, unloading, transfer, and storage activities; updating operating procedures for covered tank systems; and verifying training for employees engaged in operating or maintaining the covered tank systems. The abatement also included a Mechanical Integrity element to develop inspection and testing practices for covered tanks and covered tank systems, including piping systems, pumps, tank relief systems, emergency shutdown systems, safety-related pressure and temperature transmitters, high-level switches, LEL gas detectors, and radar level gauges.

Deliverable dates for the abatement items ranged from one year to 30 months from the effective date of the agreement, October 1, 2020. Per the abatement, ITC agreed to meet with OSHA every six months until completion of the abatement to discuss progress on the activities described above and to notify OSHA of any tanks removed from service.

4.5.1.3 Historical Problems with the Atmospheric Storage Tank Exemption

ITC took the position that the storage of the butane-enriched naphtha product in Tank 80-8 was excluded from coverage under the OSHA PSM standard based on an exemption for "flammable liquids stored in atmospheric tanks or transferred which are kept below their normal boiling point without benefit of chilling or refrigeration" that exists in the standard.[b] As previously stated, following the incident, OSHA cited the ITC Deer Park terminal for violation of its PSM standard. Following issuance of this citation, OSHA and ITC entered into a settlement agreement, whereby ITC agreed to conduct an enhanced abatement at the ITC Deer Park terminal. However,

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[a] All of the storage tanks contained in the First & Second 80's tank farm, including Tank 80-8, were removed from the facility following the incident. As such, these tanks are not included on the list.

[b] 29 C.F.R. § 1910.119(a)(1)(ii)(b)

under the settlement agreement, ITC did not concede that Tank 80-8 was covered under the OSHA PSM standard, and OSHA removed all PSM compliance-related language from the citations.

The “atmospheric storage tank exemption” is original to the OSHA PSM standard. Despite it being a point of contention and topic of debate since its inception, the exemption remains unchanged. Following promulgation of the standard, OSHA published an instructional document on September 28, 1992, entitled *29 C.F.R. §1910.119, Process Safety Management of Highly Hazardous Chemicals – Compliance Guidelines and Enforcement Procedures,* for the purpose of establishing uniform policies, procedures, standard clarifications, and compliance guidance for enforcement of the PSM standard. Appendix B of the document, *Clarifications and Interpretations of the PSM Standard*, contains guidance that “shall be followed in interpreting the PSM standard for compliance purposes.” For the purpose of interpreting the standard, OSHA stated in the document that the atmospheric storage tank exemption is applicable to “flammable liquids in tanks, containers and pipes used only for storage and transfer (to storage), and not connected to a process or a process vessel” [42, p. 93] Since that time, OSHA has published several Letters of Interpretation (LOIs) that address the exemption, as well as court rulings.

The CSB investigated two incidents, in 2001 and in 2009, in which it determined that the atmospheric storage tank PSM exemption contributed to the incidents:

- On July 17, 2001, an explosion occurred at the Motiva Enterprises LLC Delaware City Refinery (DCR) in Delaware City, Delaware [43]. One contract employee died and eight workers were injured when a spent sulfuric acid storage tank failed and released its contents, which ignited. Approximately 1.1 million gallons of spent sulfuric acid were released; 99,000 gallons reached the Delaware River. As a result of its investigation, the CSB found that Motiva did not consider the acid tank farm to be covered by requirements of the OSHA PSM standard as a result of the atmospheric storage tank exemption. The CSB stated in its report that the incident would likely not have occurred if good process safety management practices had been adequately implemented, such as mechanical integrity, MOC, and pre-startup safety review.

  The CSB issued recommendation 2001-05-I-DE-R1 to OSHA to ensure that atmospheric storage tanks interconnected with a process with at least 10,000 pounds of a flammable substance are PSM covered. At the time of writing this report, this recommendation is in “Open – Unacceptable Response” status [44].

- On October 23, 2009, a large explosion occurred at the Caribbean Petroleum Corporation (CAPECO) facility in Bayamón, Puerto Rico, during offloading of gasoline from a tanker ship, the *Cape Bruny*, to the CAPECO tank farm onshore [45]. A five-million-gallon aboveground storage tank overflowed into a secondary containment dike. The gasoline spray aerosolized, forming a large vapor cloud, which ignited after reaching an ignition source in the wastewater treatment area of the facility. The blast and fire from multiple secondary explosions resulted in significant damage to 17 of the 48 petroleum storage tanks and other equipment onsite and in neighborhoods and businesses off-site. The fires burned for almost 60 hours. As a result of its investigation, the CSB found that the U.S. regulatory system does not consider bulk aboveground storage tank terminals storing flammable liquid to be highly hazardous, even those near communities. Further, the CSB found that due to a lack of regulatory coverage under the OSHA PSM standard and the EPA RMP rule, tank terminal facilities are not required to conduct risk assessments to address flammable hazards on-site or to follow RAGAGEP.

> The CSB made recommendation 2010-02-PR-R4 to OSHA to revise the Flammable and Combustible Liquids standard (29 CFR § 1910.106), including establishing hazard analysis, management of change, and mechanical integrity management system elements for bulk aboveground storage tanks, similar to the PSM standard. At the time of writing this report, this recommendation is in "Open – Awaiting Response or Evaluation/Approval of Response" status.

On December 9, 2013, OSHA published a *Request for Information on Process Safety Management and Prevention of Major Chemical Accidents (78 FR 73746)* in response to Section 6(a) of Executive Order 13650: Improving Chemical Facility Safety and Security [38]. Within this document was a list of "Rulemaking and Enforcement Policy Change Options Under Consideration." According to this document:

> OSHA has determined that revisions to its PSM standard may be needed to address issues in coverage. As specified in Executive Order 13650, the Agency is also considering related revisions to its Explosives and Blasting Agents standard to address potential issues in coverage; updates to its Flammable Liquids standard and Spray Finishing standard to better align with current versions of applicable consensus standards; and changes in its enforcement policies for these standards.
>
> OSHA identified a number of rulemaking and policy options through the Agency's PSM NEPs, its investigation of major accidents, and its review of recommendations from the safety community. OSHA identified the following topics as potential candidates for rulemaking or enforcement policy changes:
>
> 11. Clarifying the PSM Exemption for Atmospheric Storage Tanks
>
> Pursuant to paragraph (a)(1)(ii) of Sec. 1910.119, the PSM standard applies to processes involving a flammable liquid or gas on site in one location in a quantity of 10,000 pounds or more. However, paragraph (a)(1)(ii)(B) contains an exemption for "[f]lammable liquids stored in atmospheric tanks or transferred which are kept below their normal boiling point without benefit of chilling or refrigeration."
>
> In Secretary of Labor v. Meer Corporation (1997) (OSHRC Docket No.95-0341), an administrative law judge ruled that PSM coverage does not extend to flammables stored in atmospheric tanks, even if the tanks are connected to a process. As a result, employers can exclude the amount of flammable liquid contained in an atmospheric storage tank, or in transfer to or from storage, from the quantity contained in the process when determining whether a process meets the 10,000-pound threshold quantity. The Meer decision was contrary to OSHA's earlier interpretation of paragraph (a)(1)(ii)(B), which was that the standard covered all stored flammables when connected to, or in close proximity to, a process.

> OSHA believes that revising paragraph (a)(1)(ii)(B) to include flammable liquids in atmospheric storage tanks within or connected to a PSM covered process would improve the safety of workers by remedying the issue in PSM enforcement that has existed since the Meer decision. In the questions in this RFI, the Agency requests comment on revising paragraph (a)(1)(ii)(B) to clarify that the PSM standard covers all stored flammables when connected to, or in close proximity to, a process [38].

The CSB responded to OSHA's Request for Information on March 31, 2014, with comments on several topic areas, including the exemption for atmospheric storage tanks outlined in the PSM standard [46]. In its letter, the CSB outlined why blending and mixing operations should be included in the scope of a process and urged OSHA to eliminate the atmospheric storage tank exemption and/or to revise the Flammable Liquids standard (29 C.F.R. §1910.106) to require additional safeguards for atmospheric storage tanks, including:

- Requirements for mechanical integrity during design, construction, and maintenance.
- A requirement for the conduct of written management of change analyses.
- Requirements for the installation and maintenance of an automatic liquid overfill protection system [46, p. 2].

On November 9, 2022, the CSB submitted comments on OSHA's September 20, 2022, Federal Register Notice (87 Fed. Reg. 57520) to address the agency's PSM standard modernization rulemaking project (PSM STD Modernization) [47]. The CSB urged OSHA to eliminate the atmospheric storage tank exemption, stating:

> OSHA's preamble to the PSM standard stated that the reason for the exemption is that ASTs were already regulated under 29 CFR 1910.106 Flammable liquids (106 STD). The 106 STD is intended to address fire and explosion hazards of flammable liquids, unlike the PSM standard which is to prevent or minimize the consequences of catastrophic releases of toxic, reactive, flammable, or explosive chemicals. The 106 STD contains some requirements for how ASTs will be designed but lacks mechanical integrity requirements during design, construction, and maintenance as well as management of change analysis when changes occur.
>
> Additionally, because of the AST exemption and litigation, the PSM's coverage of certain flammables above a threshold quantity does not extend to those applicable stored flammables if they are contained in ASTs, even if they are connected to a process. To address this issue the CSB issued Recommendation No. 2001-05-I-DE-R1 to OSHA from its Motiva Enterprises Sulfuric Acid Tank Explosion investigation to expand coverage under the PSM standard to include ASTs. In addition to the CSB's Motiva investigation, the AST exemption issue was a factor in the Caribbean Petroleum Refining Tank Explosion and Fire (CAPECO) investigation and the Intercontinental Terminal Company (ITC) Tank Fire investigation (pending) [47].

The CSB concludes that the atmospheric storage tank exemption in the OSHA PSM standard continues to allow for catastrophic incidents to occur because necessary safeguards are not being implemented for equipment that should otherwise be covered under the PSM standard. Examples from past CSB investigations include the July 17, 2001, Motiva Enterprises sulfuric acid tank explosion and the October 23, 2009, Caribbean Petroleum Corporation tank fire and explosion, in addition to the March 17, 2019, ITC tank fire incident discussed in this report.

Coverage under the OSHA PSM standard requires that process equipment handling highly hazardous chemicals is subject to a comprehensive PSM program that integrates technologies, procedures, and management practices to help ensure safe and healthful workplaces. Implementation of this type of program results in the addition of safeguards to ensure the equipment used to handle these chemicals continues to operate safely and as designed. These safeguards are intended to prevent or minimize the consequences of catastrophic releases of toxic, reactive, flammable, or explosive chemicals from the process equipment. OSHA defines a process as "any activity involving a highly hazardous chemical including any use, storage, manufacturing, handling, or on-site movement of such chemicals, or combination of these activities" [39].

As such, had it not been for the atmospheric storage tank exemption, Tank 80-8 and its circulation pump would have been subject to the requirements contained in the OSHA PSM standard, including the Mechanical Integrity, PHA, and MOC requirements discussed in this report. The CSB concludes that had the OSHA PSM standard applied to Tank 80-8 and its related equipment, ITC would have been required to implement a formal PSM system to provide the company with additional opportunities to identify and control hazards for Tank 80-8 and its associated equipment.

Based upon the CSB's November 9, 2022, comments to OSHA regarding the modernization of PSM specific to the difference in purposes between the 106 STD and the PSM standard, and the need to prevent or minimize the consequences of catastrophic releases posed by category 1 flammable gases and flammable liquids in aboveground storage tanks currently exempted by 29 CFR § 1910.119(a)(1)(ii)(B):

- the CSB supersedes CSB Recommendation No. 2001-05-I-DE-R1 from the Motiva Enterprises Sulfuric Acid Tank Explosion investigation and CSB Recommendation No. 2010-02-PR-R4 from the Caribbean Petroleum Refining Tank Explosion and Fire

and

- the CSB herewith recommends that OSHA eliminate the atmospheric storage tank exemption from the PSM standard (**2019-01-I-TX-R7**).

4.5.1.4 Center for Chemical Process Safety Risk Based Process Safety

Even though the PSM standard did not apply to Tank 80-8 and its associated equipment, ITC could have voluntarily chosen to apply the broadly accepted framework for process safety management contained in the CCPS's *Guidelines for Risk Based Process Safety* [48]. While the guidelines are not a requirement, the book provides 20 elements of a process safety management program to help organizations design and implement more effective process safety management systems. These elements include Hazard Identification and Risk Analysis, which correlates to the OSHA PSM element of PHA; MOC; and Asset Integrity and Reliability, which correlates to the OSHA PSM element of Mechanical Integrity.

Although ITC applied some PSM elements across its entire Deer Park terminal, such as MOC and incident investigation, the company did not apply other key elements of a comprehensive process safety management system to atmospheric storage tanks in highly hazardous chemical service, such as Tank 80-8. Examples of these elements include:

- **Asset Integrity and Reliability:** Had ITC had formal maintenance procedures and training for pump replacements, and a routine preventative maintenance program for the pumps as recommended by the pump manufacturer, ITC could have identified issues with the Tank 80-8 circulation pump before it failed within three months of installation; and
- **Hazard Identification and Risk Analysis:** Had ITC conducted a comprehensive and effective process hazard analysis on the First & Second 80's tank farm, the company could have evaluated and implemented additional engineering controls such as flammable gas detection systems, remote isolation equipment, and/or tank farm subdivisions as needed to promptly detect and secure flammable tank product leaks, slow the spread of flammable material to adjacent tanks inside the tank farm containment area, and allow emergency responders to access equipment such as fire monitors designed to respond to tank fires.

A comprehensive process safety management system would have provided the company with additional opportunities to identify and control hazards through multiple layers of protection, including the examples of preventative and mitigative safeguards discussed in this report. As such, the CSB concludes that had ITC implemented a comprehensive process safety management system that effectively identified and controlled the hazards for Tank 80-8 and its related equipment, the company could have prevented this incident. The CSB recommends that ITC develop and implement a process safety management system for the ITC Deer Park terminal applicable to all atmospheric storage tanks and associated equipment in highly hazardous chemical service. The program should follow industry guidance provided in publications such as the American Petroleum Industry's API STD 2610, *Design, Construction, Operation, Maintenance, and Inspection of Terminal and Tank Facilities* and the Center for Chemical Process Safety's *Guidelines for Risk Based Process Safety*. (**2019-01-I-TX-R1**).

KEY LESSON

Companies have a duty of care to ensure safety at facilities that handle flammable or highly hazardous substances and protect surrounding communities and the environment regardless of whether the hazardous substance(s) onsite fall under OSHA's PSM standard or EPA's RMP rule. To prevent catastrophic incidents, a company should apply a comprehensive process safety management system such as CCPS's Guidelines for Risk Based Process Safety or CCPS' Guidelines for Implementing Process Safety Management Systems.

4.5.2 EPA RISK MANAGEMENT PROGRAM (RMP) RULE

The Clean Air Act (CAA) Amendments require the EPA to promulgate regulations to prevent accidental releases of regulated substances and reduce the severity of those releases that do occur.[a] Congress provides under the CAA Amendments that the EPA must "promulgate reasonable regulations and appropriate guidance to provide, to the greatest extent practicable, for the prevention and detection of accidental releases of regulated substances and for response to such releases by the owners or operators of the sources of such releases."[b] Under the authority of the CAA section 112I, the EPA adopted the RMP regulations at 40 C.F.R. Part 68 (the RMP rule), which required compliance by 1999.

The RMP rule requires facilities that contain more than a threshold quantity of any of the listed toxic or flammable substances[c] in a process to prepare and submit to the EPA an RMP containing emergency contact information, descriptions of processes and hazardous chemicals on-site, an accident history, and worst-case release scenarios.[d] Unlike the PSM standard, the RMP rule does not include an exemption for atmospheric storage of flammable liquids [49].[e]

The RMP rule defines three different Program levels (Program 1, 2, or 3) based on a process unit's potential for impact to the public and the requirements to prevent incidents.[f] Program 3 processes are subject to additional, more stringent prevention program requirements, including: MOC reviews, mechanical integrity, training, and PHAs. These prevention program elements are based primarily on the OSHA PSM standard, and much of the language contained in each element is identical to the OSHA PSM standard.

On January 6, 1998, the EPA modified the RMP rule by adding a provision for the threshold determination of flammable substances in a mixture intended to "better focus accident prevention activities on stationary sources with high hazard operations and reduce duplication with other similar requirements."[g] This provision contained in 40 C.F.R. § 68.115(b)(2)(i) states the following:

> [I]f the concentration of the substance is one percent or greater by weight of the mixture, then, for purposes of determining whether a threshold quantity is present at the stationary source, the entire weight of the mixture shall be treated as the regulated substance unless the owner or operator can demonstrate that the mixture itself does not have a National Fire Protection Association [NFPA] flammability hazard rating of 4.[h]

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[a] See 61 FR 3667, p. 1.

[b] CAA Amendments Section 112(r)(7)(B)(i); 104 STAT 2399 Page 165. Public Law 101-549 – November 15, 1990.

[c] According to 40 CFR § 68.10(a), "[a]n owner of operator of a stationary source that has more than a threshold quantity of a regulated substance in a process, as determined under § 68.115, shall comply with the requirements of this part no later than the latest of the following dates…"

[d] See 40 CFR § 68.12. General Requirements.

[e] Section 112(r)(B)(i) states that the RMP rule "shall cover storage, as well as operations."

[f] See 40 CFR § 68.10. Applicability.

[g] 63 FR 640 – List of Regulated Substances and Thresholds for Accidental Release Prevention; Amendments.

[h] The criteria for the NFPA-4 flammability rating are contained in the 1996 edition of NFPA 704 [75], and the 1996 edition of NFPA 30 [31]. EPA's RMP rule incorporates both standards by reference. In NFPA 704, NFPA-4 rating criteria are defined as a liquid having a flash point below 73°F and boiling point below 100°F.

Prior to the incident, ITC submitted its most recent RMP to the EPA on March 12, 2018 [50]. According to the RMP, ITC was applying RMP rule requirements to certain covered processes and tanks containing regulated substances at the ITC Deer Park terminal. Specifically, ITC's RMP included covered processes containing 1,3-butadiene, 1-butene, 1,3-pentadiene, isoprene, and vinyl acetate monomer. ITC's RMP did not include the remainder of the hazardous substances stored at the terminal, including the naphtha and butane mixture contained in Tank 80-8.

According to ITC records reviewed by the CSB, Tank 80-8 contained approximately 1.4 million pounds of butane at the time of the incident, well above the threshold quantity of 10,000 pounds. ITC did not, however, include the butane and naphtha mixture contained within Tank 80-8 as a process chemical in its RMP. ITC pointed to 40 C.F.R. § 68.115(b)(2)(i) and asserted that the butane-enriched naphtha product contained in Tank 80-8 was not subject to the RMP rule because it was an NFPA-3[a] rated material rather than an NFPA-4 rated material.

The product contained in Tank 80-8 at the time of the incident contained over 8% butane by weight. ITC acknowledged that the amount of butane in the butane-enriched naphtha product exceeded 1%[b] by weight but asserted that the "mixture of chemical substances" contained in Tank 80-8 was excluded from determining whether the RMP threshold amount of butane was met under the provisions of 40 C.F.R. § 68.115(b)(2)(i). While the placard affixed to Tank 80-8 at the time of the incident displayed an NFPA flammability rating "4" for the butane-enriched naphtha product contained in the tank (see **Figure 4**), ITC provided documents showing that the material was an NFPA flammability rating "3." Although the EPA RMP rule does not regulate NFPA-3 rated liquids, these materials are hazardous based on their inherent properties. NFPA 704 states that these substances produce hazardous atmospheres with air under almost all ambient temperatures and are readily ignited under almost all conditions [51, p. 7].

The CSB has investigated several high-consequence chemical incidents that involved materials rated lower than an NFPA "4." The CSB discussed above the Motiva incident that occurred on July 17, 2001, which occurred when flammable vapors inside a storage tank containing spent sulfuric acid[c] were ignited, causing an explosion and fatally injuring one worker. Despite the severity of the incident, the Motiva SDS showed a flammability rating that can range between "0" and "3" for the spent sulfuric acid, and the tank was not covered by the EPA RMP rule [43]. Similarly, the CSB investigated the CAPECO incident discussed above, which occurred on October 23, 2009, in Bayamón, Puerto Rico. During that investigation, the CSB found that NFPA-3 rated gasoline was the source of the tremendous explosion and fire and posed a significant hazard to the environment and surrounding communities. The CSB subsequently issued Recommendation No. 2010-02-I-PR-R1 to the EPA to modify various regulations to address mixtures containing NFPA-3 rated materials. Currently that recommendation is in an "open" status, meaning it has not yet been implemented.

One of the most notable recent incidents resulting in several technical and regulatory recommendations in the United Kingdom (UK) is an explosion and fire that occurred at the Buncefield oil storage depot in Hemel Hemptstead, Hertfordshire, UK, on December 11, 2005. During this incident, a vapor cloud explosion and

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[a] The criteria for the NFPA-3 flammability rating are defined as a liquid having a flash point below 73°F and boiling point at or above 100°F, and those liquids having a flash point at or above 73°F and below 100°F.

[b] The butane added to the tank between December 2018 and March 2019 was more than 8% of the total product by weight.

[c] Spent sulfuric acid normally contains small amounts of flammable materials. Light hydrocarbons in the acid can vaporize and create a flammable atmosphere above the liquid surface if sufficient oxygen is present.

multiple tank fires occurred after a tank was overfilled with gasoline. The explosion generated significant blast pressure, resulting in additional loss of containment that led to fire and other damage involving 22 tanks. There were no fatalities, but 43 people were injured, and the damage to nearby commercial and residential property totaled $1.5 billion [52]. Similar to the CAPECO and the ITC incidents, Buncefield involved a substance (in the case of Buncefield, it was petrol, or gasoline) that is typically considered an NFPA-3 rated material [53] [54].

While the CSB is not validating ITC's NFPA "3" determination, ultimately the application of this regulatory provision resulted in ITC not developing and implementing an effective PSM program, including a comprehensive PHA and MOC review, under the RMP rule for its Tank 80-8 operations. The CSB concludes that had the EPA RMP rule applied to Tank 80-8 and its circulation pump, this incident likely would not have occurred. For example, had ITC implemented an effective process safety management program, such as what the RMP rule requires, even if the pump had leaked, additional safeguards such as flammable gas detection and remote isolation equipment should have been available to quickly identify and stop the release.

The CSB also concludes that NFPA-3 flammability rated materials have resulted in significant explosions and fires similar to those contemplated to occur from NFPA-4 rated materials. As such, the EPA RMP rule language in 40 C.F.R. § 68.115(b)(2)(i) does not appear to be in alignment with the congressional mandates set out in the Clean Air Act Amendments to prevent accidental releases and mitigate the consequences of such releases.[a]

The CSB supersedes CSB Recommendation No. 2010-02-PR-R1 from the CAPECO investigation and herewith recommends that the EPA modify 40 C.F.R. § 68.115(b)(2)(i) to expand coverage of its RMP rule to include all flammable liquids, including mixtures, with a flammability rating of NFPA-3 or higher (**2019-01-I-TX-R8**).

5 CONCLUSIONS

5.1 FINDINGS

1. The butane-enriched naphtha product release initiated when the Tank 80-8 circulation pump's gland nuts loosened from the seal chamber cover, allowing the seal gland to separate from the seal chamber cover and consequently creating a path for butane-enriched naphtha product to release.

2. Tank 80-8's circulation pump likely continued to operate past the point of outboard bearing failure while circulating the butane-enriched naphtha product. The bearing failure likely led to significant pump vibration, which loosened the gland nuts that secured the mechanical seal in place, causing the seal to separate and allow the release of the flammable mixture.

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[a] The CSB also notes that in response to this incident, the TCEQ issued a proposed rulemaking entitled *Chapter 338 – Aboveground Storage Vessel Safety Program*. This proposed rule, which is supposed to be adopted as a final rule in the fall of 2023, would provide additional requirements for certain aboveground storage vessels. It proposes to incorporate by reference certain sections of the EPA RMP rule, including the NFPA flammable rating provision at 40 C.F.R. § 68.115(b)(2)(i). As such, had TCEQ's proposed rule been in effect at the time of the incident, it would not have applied to ITC's Tank 80-8. The proposed rule would apply to Tank 80-8, however, if EPA would modify 40 C.F.R. § 68.115(b)(2)(i) to expand coverage to include all flammable liquids, including mixtures, with an NFPA-3 flammability rating or higher.

3. Accumulated flammable vapors in the area around the Tank 80-8 pump skid were likely ignited as a result of heat generated from the metal-to-metal contact between the unrestrained seal gland and pump shaft.

4. The ITC Deer Park terminal's management systems lacked essential mechanical integrity program items, such as maintenance procedures, training for pump replacements and rebuilds, and routine preventative maintenance activities as recommended by the pump manufacturer, for equipment in highly hazardous chemical service that was not covered by OSHA PSM or EPA RMP requirements. A formal mechanical integrity program for all pumps in highly hazardous chemical service could have prevented this incident by allowing ITC to have additional opportunities to identify Tank 80-8's circulation pump issues prior to the incident.

5. ITC did not retrofit the Tank 80-8 circulation pump with vibration monitoring equipment, which resulted in pump vibration going undetected and allowed the outboard bearing to continue to degrade to failure. Had ITC installed vibration monitoring equipment on the Tank 80-8 circulation pump, excessive vibration likely would have triggered an alarm, and ITC operators could have shut down the pump before the bearing failed, preventing the butane-enriched naphtha product release.

6. Had Tank 80-8 been subject to the OSHA PSM standard and/or the EPA RMP rule, ITC would have been required to track the recommendation to install a flammable gas detection system such as an LEL detector or deluge system at the Tank 80-8 circulation pump to completion and document the resolution in a timely manner.

7. Had a flammable gas detection system existed in the vicinity of the Tank 80-8 circulation pump, it could have provided adequate time for personnel to detect and attempt to secure the butane-enriched naphtha product release before its flammable vapors eventually ignited.

8. Terminals and tank facilities that store flammable substances should develop, implement, and maintain flammable gas detection systems to alert workers to hazardous conditions and allow them to respond in a timely manner.

9. Had Tank 80-8 been equipped with a remotely operated emergency isolation valve (ROEIV), the butane-enriched naphtha product release could have been secured without the need for personnel to enter the tank farm, allowing emergency responders to extinguish the initial fire early in the response.

10. Had remotely operated emergency isolation valves (ROEIVs) configured to "Fail-Closed" been installed on Tank 80-8 and the other fourteen tanks in First & Second 80's tank farm, the tanks could have been secured without the need for personnel to enter the tank farm after power was lost to all motor operated valves (MOVs), and the quantity of the materials released could have been reduced.

11. Although the First & Second 80's tank farm was designed in accordance with applicable NFPA 30 tank farm spacing requirements in place at the time the tank farm was constructed, the NFPA 30 recommendation for additional spacing for compacted tank farm layouts was not included in the design. This design, which allowed for reliance on administrative controls and emergency response, allowed the Tank 80-8 fire to spread and involve additional tanks in the tank farm.

12. ITC's First & Second 80's tank farm was not subdivided as was required by NFPA 30. Although the subdivisions of the diking required by NFPA 30 likely would have been insufficient to hold the full contents of

Tank 80-8, additional subdivisions could have slowed the spread of the butane-enriched naphtha product and allowed responders the opportunity to access and activate the fixed fire monitors located within the containment area to fight the fire surrounding the Tank 80-8 piping manifold before it spread to adjacent tanks.

13. Had ITC implemented additional engineering safeguards, such as flammable gas detection systems and remotely operated emergency isolation valves (ROEIVs), to mitigate the risks of operating the Tank 80-8 circulation pump inside the secondary containment area, the spread of the initial fire could have been slowed or prevented.

14. The accumulation of hydrocarbon products, firefighting foam, and contaminated water within the First & Second 80's tank farm containment area contributed to the fire spreading to additional tanks in the common containment area. The accumulation likely also contributed to the containment wall failure, which allowed a mixture of hydrocarbon products, firefighting foam, and contaminated water to be released into the local waterways.

15. The atmospheric storage tank exemption in the OSHA PSM standard continues to allow for catastrophic incidents to occur because necessary safeguards are not being implemented for equipment that should otherwise be covered under the PSM standard. Examples from past CSB investigations include the July 17, 2001, Motiva Enterprises sulfuric acid tank explosion and the October 23, 2009, Caribbean Petroleum Corporation tank fire and explosion, in addition to the March 17, 2019, ITC tank fire incident discussed in this report.

16. Had the OSHA PSM standard applied to Tank 80-8 and its related equipment, ITC would have been required to implement a formal PSM system to provide the company with additional opportunities to identify and control hazards for Tank 80-8 and its related equipment.

17. Had ITC implemented a comprehensive process safety management system that effectively identified and controlled the hazards for Tank 80-8 and its associated equipment, the company could have prevented this incident.

18. Had the EPA RMP rule applied to Tank 80-8 and its circulation pump, this incident likely would not have occurred. For example, had ITC implemented an effective process safety management program, such as what the RMP rule requires, even if the pump had leaked, additional safeguards such as flammable gas detection and remote isolation equipment should have been available to quickly identify and stop the release.

19. NFPA-3 flammability rated materials have resulted in significant explosions and fires similar to those contemplated to occur from NFPA-4 rated materials. As such, the EPA RMP rule language in 40 C.F.R. § 68.115(b)(2)(i) does not appear to be in alignment with the congressional mandates set out in the Clean Air Act Amendments to prevent accidental releases and mitigate the consequences of such releases.

5.2 CAUSE

The CSB determined that the cause of the incident was the release of flammable butane-enriched naphtha vapor from the failed Tank 80-8 circulation pump, which accumulated in the area and ignited, resulting in a fire. Contributing to the severity of the incident were the absence of a flammable gas detection system to alert the operators to the flammable mixture before it ignited approximately 30 minutes after the release began, and the absence of remotely operated emergency isolation valves (ROEIVs) to safely secure the flammable liquids in Tank 80-8 and the surrounding tanks in the First & Second 80's tank farm.

Elements of the tank farm design, including tank spacing, subdivisions, engineering controls for pumps located inside the containment area, and drainage systems also contributed to the severity of the incident by allowing the fire to spread to other tanks within the tank farm. The resulting accumulation of hydrocarbon and petrochemical products, firefighting foam, and contaminated water in the secondary containment area ultimately contributed to a breach of the containment wall and a release of materials to the local waterways.

Finally, the CSB determined that because of the atmospheric storage tank exemption contained in the OSHA PSM standard and the flammability exemption contained in the EPA RMP rule, ITC was not required to develop and implement a formal PSM program for Tank 80-8 and its associated equipment that could have provided a process to identify and control the specific hazards that resulted in this incident, which also contributed to this incident.

6 RECOMMENDATIONS

To prevent future chemical incidents, and in the interest of driving chemical safety excellence to protect communities, workers, and the environment, the CSB makes the following safety recommendations:

6.1 PREVIOUSLY ISSUED RECOMMENDATION SUPERSEDED BY THIS REPORT

6.1.1 TO OSHA FROM THE MOTIVA ENTERPRISE SULFURIC ACID TANK EXPLOSION INVESTIGATION

2001-05-I-DE-R1

Ensure coverage under the Process Safety Management Standard (29 CFR 1910.119) of atmospheric storage tanks that could be involved in a potential catastrophic release as a result of being interconnected to a covered process with 10,000 pounds of a flammable substance.

*Superseded by **2019-01-I-TX-R8** to OSHA in Section 6.2.3 below**.***

6.1.2 TO OSHA FROM THE CARIBBEAN PETROLEUM REFINING TANK EXPLOSION AND FIRE INVESTIGATION

2010-02-PR-R4

Revise the Flammable and Combustible Liquids standard (29 CFR § 1910.106) to require installing, using, and maintaining a high-integrity automatic overfill prevention system with a means of level detection, logic/control equipment, and independent means of flow control for bulk aboveground storage tanks containing gasoline, jet fuel, other fuel mixtures or blendstocks, and other flammable liquids having an NFPA 704 flammability rating of 3 or higher, to protect against loss of containment. At a minimum, this system shall meet the following requirements:

1. Separated physically and electronically and independent from the tank gauging system.
2. Engineered, operated, and maintained to achieve an appropriate level of safety integrity in accordance with the requirements of Part 1 of International Electro-technical Commission (IEC) 61511-SER ed1.0B-2004, Functional Safety – Safety Instrumented Systems for the Process Industry Sector. Such a system would employ a safety integrity level (SIL) documented in accordance with the principles in Part 3 of IEC 61511-SER ed1.0B-2004, accounting for the following factors:
    i. The existence of nearby populations and sensitive environments;
    ii. The nature and intensity of facility operations;
    iii. The extent/rigor of operator monitoring.
3. Proof tested in accordance with the validated arrangements and procedures with sufficient frequency to ensure the specified safety integrity level is maintained.

b) Establish hazard analysis, management of change and mechanical integrity management system elements for bulk aboveground storage tanks in the revised 1910.106 standard that are similar to those in the Process Safety Management of Highly Hazardous Chemicals standard (29 CFR § 1910.119) and ensure these facilities are subject to Recognized and Generally Accepted Good Engineering Practices (RAGAGEP).

*Superseded by **2019-01-I-TX-R8** to OSHA in Section 6.2.3 below**.***

6.1.3 TO EPA FROM THE CARIBBEAN PETROLEUM REFINING TANK EXPLOSION AND FIRE INVESTIGATION

2010-02-I-PR-1

Revise where necessary the Spill Prevention, Control and Countermeasure (SPCC); Facility Response Plan (FRP); and/or Accidental Release Prevention Program (40 CFR Part 68) rules to prevent impacts to the environment and/or public from spills, releases, fires, and explosions that can occur at bulk aboveground storage facilities storing gasoline, jet fuels, blendstocks, and other flammable liquids having an NFPA 704 flammability rating of 3 or higher.

At a minimum, these revisions shall incorporate the following provisions:

a) Ensure bulk aboveground storage facilities conduct and document a risk assessment that takes into account the following factors:

1. The existence of nearby populations and sensitive environments;

2. The nature and intensity of facility operations;
3. Realistic reliability of the tank gauging system; and
4. The extent/rigor of operator monitoring.

b) Equip bulk aboveground storage containers/tanks with automatic overfill prevention systems that are physically separate and independent from the tank level control systems.

c) Ensure these automatic overfill prevention systems follow good engineering practices.

d) Engineer, operate, and maintain automatic overfill prevention systems to achieve appropriate safety integrity levels in accordance with good engineering practices, such as Part 1 of International Electrotechnical Commission (IEC) 61511-SER ed1.0B-2004, Functional Safety – Safety Instrumented Systems for the Process Industry Sector.

e) Regularly inspect and test automatic overfill prevention systems to ensure their proper operation in accordance with good engineering practice.

*Superseded by **2019-01-I-TX-R9** to EPA in Section 6.2.4 below**.***

6.2 NEW RECOMMENDATIONS

6.2.1 INTERCONTINENTAL TERMINALS COMPANY, LLC (ITC)

2019-01-I-TX-R1

Develop and implement a process safety management system for the ITC Deer Park terminal applicable to all atmospheric storage tanks and associated equipment in highly hazardous chemical service. The program should follow industry guidance provided in publications such as the American Petroleum Industry’s API STD 2610, *Design, Construction, Operation, Maintenance, and Inspection of Terminal and Tank Facilities* and the Center for Chemical Process Safety’s *Guidelines for Risk Based Process Safety*.

2019-01-I-TX-R2

Develop and implement a condition monitoring program for all pumps in highly hazardous chemical service at the ITC Deer Park terminal. Ensure that condition monitoring equipment is programmed with control limits, including but not limited to vibration, consistent with ANSI/HI 9.6.9.-2018, that trigger alarms when control limits are exceeded, and that operating procedures and training reflect the appropriate actions to take when an alarm is triggered.

2019-01-I-TX-R3

Install flammable gas detection systems with associated alarm functions in product storage and transfer areas at the ITC Deer Park terminal where flammable substance releases could occur. Develop and implement a response plan and operator training for actions to take when an alarm sounds.

2019-01-I-TX-R4

Install remotely operated emergency isolation valves configured to "Fail-Closed" for all atmospheric storage tanks that contain highly hazardous chemicals or liquids with a flammability rating of NFPA-3 or higher at the ITC Deer Park terminal.

2019-01-I-TX-R5

Conduct an evaluation of the design of all new and existing tank farms at the ITC Deer Park terminal against the applicable sections of the Third Edition of API STD 2610, *Design, Construction, Operation, Maintenance, and Inspection of Terminal and Tank Facilities* and the 2021 Edition of NFPA 30, *Flammable and Combustible Liquids Code*. At a minimum the evaluation should include, but is not limited to the following sections of API STD 2610:

Section 4	Site Selection and Spacing Requirements
Section 7	Fire Prevention and Protection
Section 8.1	Aboveground Petroleum Storage Tanks
Section 9	Dikes and Berms
Section 10	Pipe, Valves, Pumps, and Piping Systems
Section 11	Loading, Unloading, and Product Transfer Facilities

and the following chapters of NFPA 30:

Chapter 21	Storage of Ignitible (Flammable or Combustible) Liquids in Tanks – Requirements for All Storage Tanks and
Chapter 22	Storage of Ignitible (Flammable or Combustible) Liquids in Tanks – Aboveground Storage Tanks

The evaluation should identify additional engineering controls needed to address minimal tank spacing, subdivisions between tanks, and placement of process equipment in containment areas. In addition, the evaluation should assess the adequacy of the containment wall and drainage system designs, accounting for the impact of firefighting activities, including the application of firewater and foam on these systems. Develop and implement recommendations based on findings from the evaluation.

6.2.2 AMERICAN PETROLEUM INSTITUTE (API)

2019-01-I-TX-R6

Update API STD 2610, *Design, Construction, Operation, Maintenance, and Inspection of Terminal and Tank Facilities,* or other appropriate products to include flammable gas detection systems within the leak detection section or where appropriate. The discussion of flammable gas and/or leak detection should address both engineering and administrative controls, including actions associated with responding to a catastrophic or emergency leak.

6.2.3 OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION (OSHA)

2019-01-I-TX-R7

Eliminate the atmospheric storage tank exemption from the PSM standard.

6.2.4 ENVIRONMENTAL PROTECTION AGENCY (EPA)

2019-01-I-TX-R8

Modify 40 C.F.R. § 68.115(b)(2)(i) to expand coverage of the RMP rule to include all flammable liquids, including mixtures, with a flammability rating of NFPA-3 or higher.

7 KEY LESSONS FOR THE INDUSTRY

To prevent future chemical incidents, and in the interest of driving chemical safety excellence to protect communities, workers, and the environment, the CSB urges companies to review these key lessons:

1. While most hazard and risk assessments consider the risk of single failures at a time, it is important for companies to realize that major incidents happen when multiple failures occur. To prevent these catastrophic events from occurring, companies should ensure the appropriate number of layers of protection are in place to mitigate the likelihood and reduce the severity of events when they do occur. Therefore, when determining when, how, or whether to complete the recommendations from hazard assessments, companies should ensure the appropriate number of preventative and mitigative safeguards are in place such that a single failure of a preventative or mitigative safeguard will not result in a catastrophic event. Leadership should ensure adequate safeguards are in place, as soon as practicable, for hazards identified by the team, especially when engineering controls are recommended and not yet installed.

2. Terminals and storage tank facilities that handle large volumes of flammable or highly hazardous substances should implement flammable gas detection systems to protect personnel, property, and neighboring communities from the potential consequences of an accidental release. These types of systems should be installed in areas around pumps, seals, flanges, and other common leak locations. These systems should be adequately designed, maintained, inspected, and tested to ensure reliability. Inspection and testing frequencies must be established to ensure the system provides adequate warning of the presence of flammable substances.

3. Companies that handle large volumes of flammable or highly hazardous substances should assess their capability to remotely isolate these substances in the event of a loss of containment. Aboveground atmospheric storage tanks that contain large volumes of these substances should be equipped with

remotely operated emergency isolative valves (ROEIVs) so that releases can be mitigated quickly and remotely from a safe location. The ROEIVs should be equipped with fusible links or configured to automatically close in the event of a power outage or other event ("Fail-Closed").

4. NFPA 30 provides safeguards to reduce the hazards associated with the storage, handling, and use of flammable and combustible liquids, including tank farm design and spacing requirements. While NFPA 30 defines minimum requirements for tank farm design and spacing, other voluntary industry guidance documents including FM Global Loss Prevention Data Sheet (FM LPDS) 7-88, *Outdoor Ignitable Liquid Storage Tanks*; and API RP 2021, *Management of Atmospheric Tank Fires*; and API STD 2610, *Design, Construction, Operation, Maintenance and Inspection of Terminals and Tank Facilities* provide more robust tank farm design criteria.

5. Companies have a duty of care to ensure safety at facilities that handle flammable or highly hazardous substances and protect surrounding communities and the environment regardless of whether the hazardous substance(s) onsite fall under OSHA's PSM standard or EPA's RMP rule. To prevent catastrophic incidents, a company should apply a comprehensive process safety management system such as CCPS's *Guidelines for Risk Based Process Safety* or CCPS' *Guidelines for Implementing Process Safety Management Systems*.

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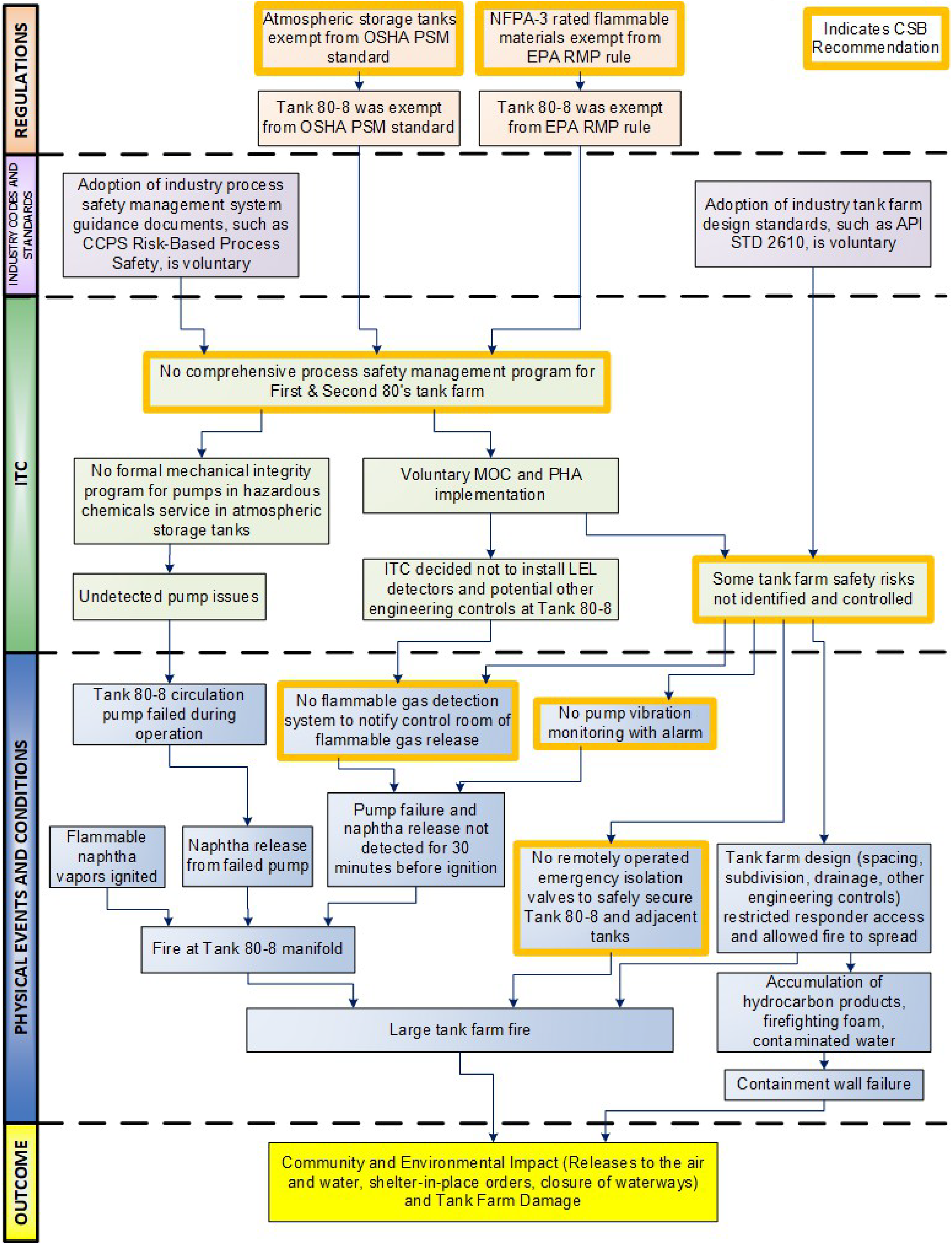
APPENDIX A—SIMPLIFIED CAUSAL ANALYSIS (ACCIMAP)



APPENDIX B—DESCRIPTION OF SURROUNDING AREA

The demographic information of the population residing within roughly a three- mile of the ITC Deer Park terminal is contained below in **Figure 32** and **Figure 33**.

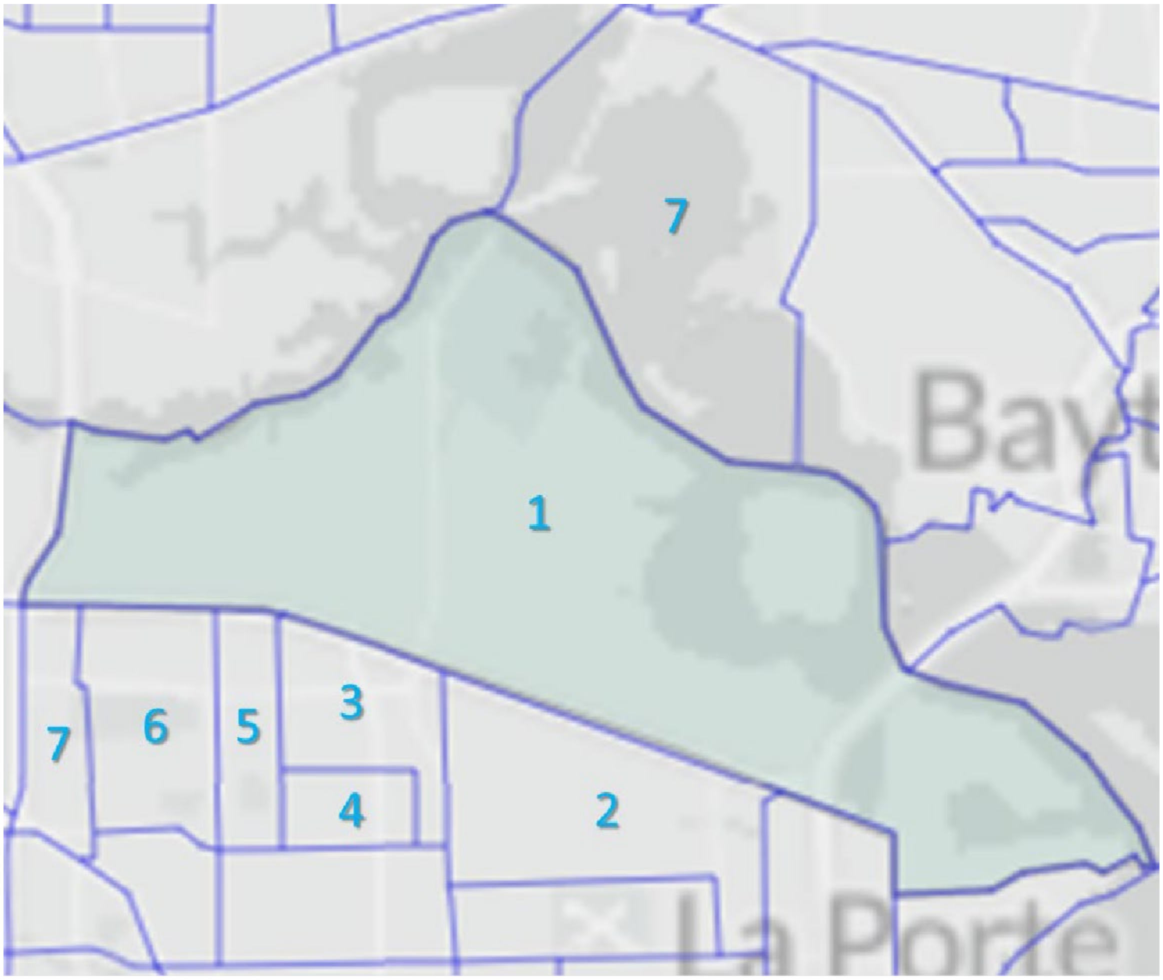


Figure 32. Census tracts contained in roughly three-mile radius of the ITC Deer Park terminal. (Credit: Census Reporter, annotations by CSB)

Tract Number	Population	Median Age	Race and Ethnicity		Per Capita Income	% Poverty	Number of Housing Units	Types of Structures	
1	0	0	0%	White	$ -	0.0%	0	0%	Single Unit
			0%	Black				0%	Multi-Unit
			0%	Native				0%	Mobile Home
			0%	Asian				0%	Boat, RV, van, etc.
			0%	Islander					
			0%	Other					
			0%	Two+					
			0%	Hispanic					
2	5,189	36	57%	White	$ 81,586	14.6%	1,578	86%	Single Unit
			1%	Black				0%	Multi-Unit
			0%	Native				13%	Mobile Home
			0%	Asian				2%	Boat, RV, van, etc.
			0%	Islander					
			0%	Other					
			0%	Two+					
			41%	Hispanic					
3	3,052	37.2	86%	White	$ 44,158	2.6%	1,020	94%	Single Unit
			0%	Black				0%	Multi-Unit
			0%	Native				6%	Mobile Home
			0%	Asian				0%	Boat, RV, van, etc.
			0%	Islander					
			0%	Other					
			2%	Two+					
			12%	Hispanic					
4	5,181	36.2	58%	White	$ 43,137	4.5%	1,911	100%	Single Unit
			3%	Black				0%	Multi-Unit
			0%	Native				0%	Mobile Home
			4%	Asian				0%	Boat, RV, van, etc.
			0%	Islander					
			0%	Other					
			6%	Two+					
			28%	Hispanic					
5	5,007	33.2	60%	White	$ 31,112	11.4%	1,774	83%	Single Unit
			1%	Black				15%	Multi-Unit
			0%	Native				1%	Mobile Home
			2%	Asian				0%	Boat, RV, van, etc.
			0%	Islander					
			0%	Other					
			1%	Two+					
			35%	Hispanic					
6	5,889	42.1	54%	White	$ 33,520	5.4%	2,296	78%	Single Unit
			0%	Black				22%	Multi-Unit
			0%	Native				0%	Mobile Home
			0%	Asian				0%	Boat, RV, van, etc.
			0%	Islander					
			0%	Other					
			1%	Two+					
			45%	Hispanic					
7	3,616	42.3	47%	White	$ 38,386	5.1%	1,342	95%	Single Unit
			1%	Black				0%	Multi-Unit
			0%	Native				4%	Mobile Home
			1%	Asian				1%	Boat, RV, van, etc.
			0%	Islander					
			0%	Other					
			1%	Two+					
			50%	Hispanic					

Figure 33. Tabulation of demographic data for the populations within the census tracts shown in **Figure 32**. (Credit: CSB)

APPENDIX C—INCIDENT TIMELINE

Date	**Time** *(approximate)*	**Event**
3/16/2019	6:54 p.m.	Tank 80-8 circulation pump started
	7:23 – 8:15 p.m.	First butane delivery completed
	9:30 – 10:29 p.m.	Second butane delivery completed
3/17/2019	7:25 – 8:45 a.m.	DCS data indicates pump discharge pressure increase
	9:30 – 10:00 a.m.	DCS data indicates tank level, pump discharge pressure decreases
	10:00 a.m.	Security camera captures footage of fire in tank farm
	10:01 a.m.	DCS communication lost for Tank 80-8 circulation pump
	10:03 a.m.	Security officer sounded fire alarm, ERT response begins
	10:05 a.m.	Announcement over all-call system
	10:10 a.m.	E-notify message sent over computer system
	12:09 p.m.	Power loss in tank farm; all DCS communication lost
	Before 1:00 p.m.	City of Deer Park issued a precautionary shelter-in-place order
	3:00 p.m.	Tank 80-5, containing xylene, ignited
3/18/2019	1:30 a.m.	Fire continues; eight storage tanks on fire
	Before 5:30 a.m.	Additional toluene tank (80-13) caught on fire but extinguished
	3:00 p.m.	Six tanks involved in fire
	4:00 p.m.	Reduction in water pressure due to malfunction of two third-party fireboard pumps and an increased demand of water supply Tanks 80-9 and 80-12 re-ignite, total of eight tanks on fire
	5:00 p.m.	ITC contacts US Fire Pump for assistance
	10:00 p.m.	Full water pressure restored
3/19/2019	12:13 a.m.[a]	ITC and US Fire Pump signed agreement; US Fire Pump mobilized from Louisiana
	After 2:30 a.m.	Second temporary reduction in water pressure Two additional tanks (80-14 and 80-15) caught fire Tanks 80-9 and 80-12 collapsed, their fires extinguished
	6:48 a.m.	US Fire Pump arrived on-scene with additional resources
	1:00 p.m.	US Fire Pump resources actively engaged alongside local responders
	After 1:00 p.m.	Tanks 80-4 and 80-7 caught fire
	3:45 p.m.	Tanks 80-11, 80-14, 80-15 extinguished Seven tanks still on fire (80-2, 80-3, 80-4, 80-5, 80-6, 80-7, 80-8)
	9:45 p.m.	Four tanks on fire (80-2, 80-3, 80-5, 80-6)
3/20/2019	3:00 a.m.	Fires extinguished
	5:20 p.m.	Tank 80-5 flare-up; responders were able to contain quickly

---

[a] US Fire Pump headquarters is located in Holden, Louisiana.

3/21/2019	Between 4:02 and 8:23 a.m.	Elevated levels of benzene detected in the northern portion of Deer Park; City of Deer Park issued a precautionary shelter-in-place order
	Morning	ITC began moving product out of the compromised tanks
	11:40 a.m.	Shelter-in-place order lifted
3/22/2019	12:15 p.m.	Secondary containment wall partially collapsed; ITC recommended shelter-in-place
	3:40 p.m.	Tanks 80-2, 80-3, 80-5 re-ignited; extinguished in roughly one hour
3/23/2019	4:00 a.m.	Containment wall secured
		Recovery of released hydrocarbon and petrochemical products, foam, and water from the tank farm and the adjacent drainage ditch began
		Spill containment and clean-up operations to remove the released products from Tucker Bayou and the Houston Ship Channel began
4/1/2019		ITC issued public statement indicating that the tank farm was stable; Nine tanks secured (removed remaining product)
5/20/2019[a]		Clean-up operations of all shoreline segments (except Tucker Bayou) complete
6/19/2019		Incident transitioned from emergency phase to long-term remediation phase
7/29/2019		Deconstruction and cleaning of all 15 tanks complete

---

[a] On June 19, 2019, Unified Command partners agreed that Tucker Bayou would be transitioned and addressed under a long-term remediation phase and not part of the emergency response phase.

APPENDIX D—FIRE PROTECTION EVALUATION REPORT

APPENDIX E—ATLAS ENGINEERING REPORT

Access both appendices from the CSB website:

https://www.csb.gov/intercontinental-terminal-company-itc-tank-fire

U.S. Chemical Safety and Hazard Investigation Board

Members of the U.S. Chemical Safety and Hazard Investigation Board:

Steve Owens
Chairperson

Sylvia E. Johnson, Ph.D.
Member

Catherine J.K.
Sandoval Member

Report

FIRE PROTECTION EVALUATION REPORT

PERSPECTIVES ON TANK FARM FIRE ITC DEER PARK (TEXAS), MARCH 2019

PREPARED FOR

US Chemical Safety and Hazard
Investigation Board
1751 Pennsylvania Avenue NW
Washington, DC 20006

Project #: 1DVT00155.000

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PREPARED BY

David Tomecek, PE FSFPE 10170
Church Rach Way, Suite 200
Westminster, Colorado 80031
(Main Report)

Jonathan Hodges, PhD 3610 Commerce
Drive, Suite 817
Baltimore, Maryland 21227
(Appendix)

PEER REVIEWED BY

Andrew Taggart, PE (Main Report) Leonard Deonarine, CEM
MEMS (Main Report)
Anil Kapahi, PhD (Appendix)

jensenhughes.com

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Abbreviations & Acronyms

API	American Petroleum Institute
CSB	United States Chemical Safety and Hazard Investigation Board
FM	Factory Mutual (currently FM Global)
HCFMO	Harris County Fire Marshal's Office
ITC	Intercontinental Terminals Company, LLC
LPDS	Loss Prevention Data Sheet
NFPA	National Fire Protection Association
Pub	Publication
PSM	Process Safety Management
RP	Recommended Practice

Definitions

Below are definitions for terms that may not be familiar to most readers and are provided for clarity. The source of each definition is provided in brackets after each term.

Containment area – The space surrounded by structures, typically called dikes or berms, intended to contain hazardous liquids. [Modified from FM Global and NFPA definitions for dike]

Boil-Over – An event in the burning of certain oils in an open-top tank when, after a long period of quiescent burning, there is a sudden increase in fire intensity associated with expulsion of burning oil from the tank. [NFPA 30, *Flammable and Combustible Liquids Code*]

Fire Hydrant – A valved connection on a water supply system having one or more outlets and that is used to supply hose and fire department pumpers with water. [NFPA 24, *Standard for the Installation of Private Fire Service Mains and their Appurtenances*] See figures for common fire hydrant types (all courtesy Mueller Company).

Dry-Barrel Hydrant

Wet-Barrel Hydrant

Post (Dry-Barrel) Hydrant

Dry-Barrel Hydrant with Integral Monitor Mount

Firefighting Tactics

Offensive Firefighting – The mode of manual firefighting in which manual fire suppression activities are concentrated on reducing the size of a fire to accomplish extinguishment. [NFPA 600, *Standard on Facility Fire Brigades*]

Defensive Firefighting – The mode of manual fire control in which the only fire suppression activities taken are limited to those required to keep a fire from extending from one area to another. [NFPA 600, *Standard on Facility Fire Brigades*]

Monitor – A fixed master stream device, manually or remotely controlled, or both, capable of discharging large volumes of water or foam. [NFPA 1964, *Standard for Spray Nozzles and Appliances*] See figures below for common monitor types. (Photos courtesy of companies identified.)

Fixed Monitor (Yellow Piping) with Nozzle (Bronze) [Sanco SpA]

Portable Monitor (Red Piping) with Nozzle (Black) [Rosenbauer]

Fire Apparatus Mounted Monitor with Large Capacity Nozzle (S&H Products, Inc.)

Trailer Mounted Monitor with Large Capacity Nozzle (William Fire & Hazard Control

1.0 Introduction

At the request of the US Chemical Safety and Hazard Investigation Board (CSB), Jensen Hughes was requested to provide wide-ranging input and discussion related to the Intercontinental Terminals Company, LLC (ITC) tank farm fire events that occurred from Sunday, March 17, 2019, through Saturday, March 23, 2019.

The information presented in this document is a combination of general requests made in the contractual scope of work identified by the CSB, as well as those items identified during subsequent discussions between the CSB and Jensen Hughes.

This report is not intended to be an in-depth investigation or report of finding, but instead provides information to the CSB team for consideration alongside other data outside the purview of Jensen Hughes. The information contained herein is based upon information provided by CSB, contained in contemporaneous information obtained from public sources (such as press releases, ITC documents made public, etc), published as accounts or interpretation in recognized periodicals or obtained via similar sources. Information obtained by sources such as social media, accounts, or assemblages of information on personal or corporate websites, advertising or opinion-editorial (op-ed) writings and similar publications were treated as speculative or unsubstantiated unless sufficient confirmatory information was obtained from fact-based sources.

2.0 General Information

On the morning of March 17, 2019, a fire initiated at the Deer Park, Texas terminal owned and operated by ITC, specifically within the "First and Second 80's" tank farm, which is located on the south side of the ITC site. Figure 1 provides an aerial view of the ITC Deer Park terminal prior to the fire (obtained via Google Earth Pro software), while Figure 2 provides a closeup of the "First and Second 80's" tank farm where the fire occurred.

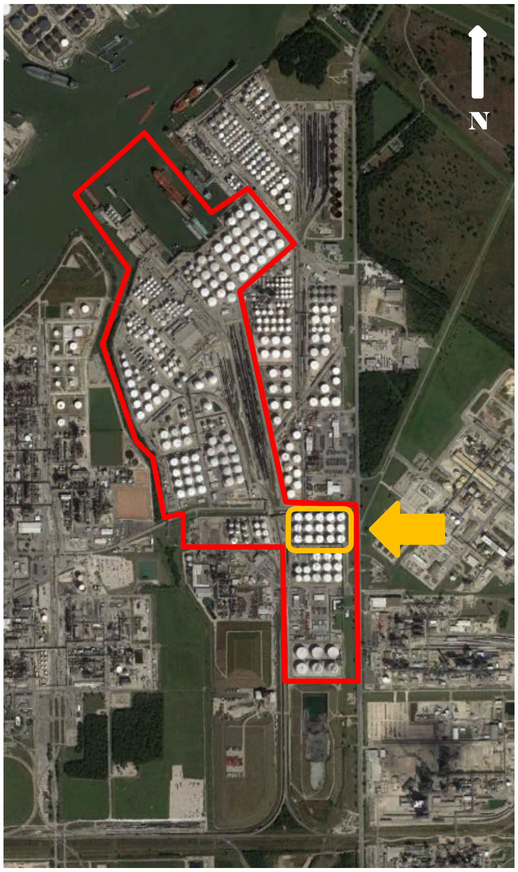

Figure 1: ITC Deer Park, Texas Facility with "First and Second 80's" Tank Farm Highlighted (Imagery Date: October 28, 2017) [Source: Google Earth Pro]

Figure 2: "First and Second 80's Tank Farm" (Imagery Date: October 28, 2017) [Source: Google Earth Pro]
(Tank farm encircled in red. Area of suspected origin identified via blue cloud. Tank 80-8 highlighted in green.)

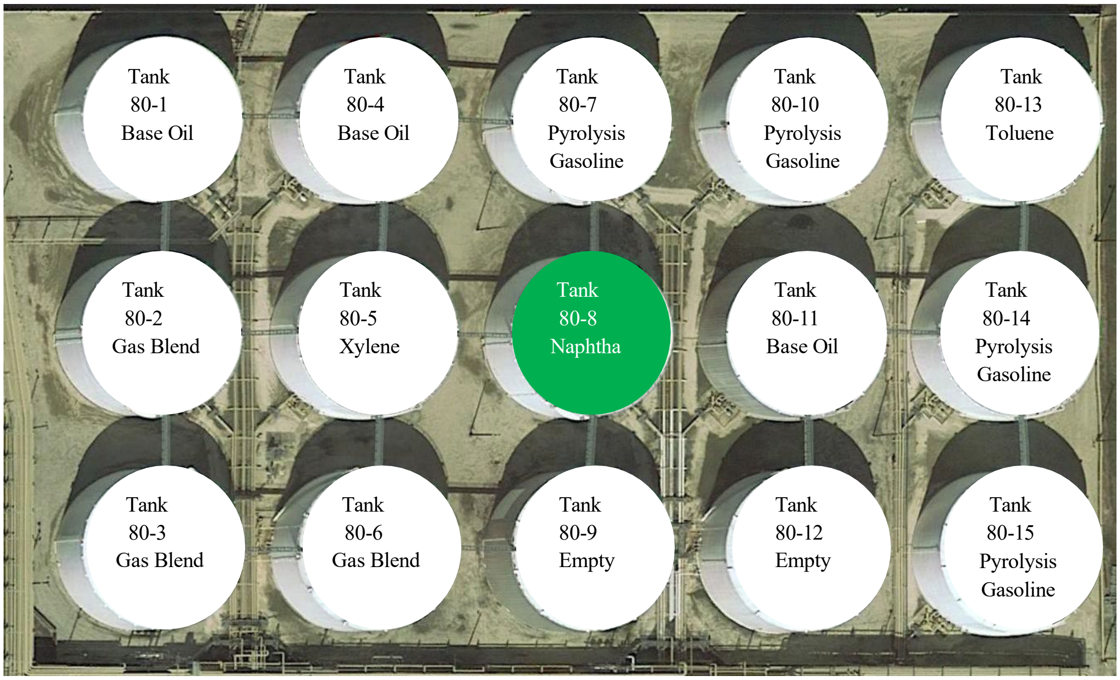

Figure 3: "First and Second 80's Tank Farm" Tank Numbers and Contents at Time of Fire (Imagery Date: October 28, 2017) [Source: Google Earth Pro, Contents from ITC Press Releases] (Tank 80-8 highlighted in green.)

3.0 Facility and Tank Farm Development Information

Intercontinental Terminals Company (ITC) was founded as a division of Mitsui & Company (USA), Inc. on February 24, 1972. Over the next few years, acquisitions and leases were focused at the north portion of the site, primarily for the wharves, warehouses and support facilities located in that area. In 1974, approximately 135 acres south of Tidal Road, which were non-contiguous to the existing acquisitions to the north, were obtained from Rollins Environmental Services. Based on the description, this purchase appears to include the area of land where the “First and Second 80’s” tank farm was constructed. [ITC Deer Park History, 2020]

Construction and operating permits from the Texas Air Control Board for Tanks 80-1 through 80-12, are dated June 17, 1976 [Texas Air Control Board, 1976; 1977; 1978 and 1985]. Tank data plates recovered from post- fire debris show that Tank 80-8 was made in 1977 and suggest that construction of the tanks began soon after permits were issued. An aerial view of the facility from December 1978, shown in Figures 4 and 5 below, indicates Tanks 80-4 through 80-15 as being complete, as well as substantial completion of Tanks 80-1 through 80-3 [Google Earth, 2019]. Additionally, tanks to the south, Tanks 80-19 through 80-22, are identified to be under construction, and storage Spheres 25-1 through 25-4 and 50-1 are also constructed on the ITC property. Aerial photographs from December 1989 indicate Tanks 80-16 through 80-24 were complete, as was the Tank 160-series tank farm further south and the Sphere 36-series vessels to the west [Google Earth, 2019]. Aerial imagery from January 14, 1995, indicates Tank 80-34 and Tanks 60-1 through 60-3 were installed, effectively completing the current configuration of the site south of Tidal Road, as depicted in Figures 1 and 2 [Google Earth, 2019].

Tank 80-8 and its counterparts in the “First and Second 80’s” tank farm were 80,000 barrel capacity tanks, with a diameter of 110 feet and a height of 48 feet, based on the recovered data plate and documents provided by ITC Deer Park. With the exception of Tanks 80-9, 80-11 and 80-12, tanks in the farm were provided with an internal floating roof and an external cone roof. Tanks 80-9, 80-11 and 80-12 were provided only with a cone roof. [Texas Air Control Board, 1976a; ITC, 2019a]. At the time of the fire, Tanks 80-9 and 80-11 were provided with insulation, while the remainder are uninsulated. The insulation consisted of polyisocyanurate panels clad with aluminum jacket [ITC, 2019a].

The overall tank farm has approximate dimensions of 449 feet (north-south) by 732 feet (east-west) on the interior of the containment area, which was constructed at the same time as the tank farm based on the aerial photographs noted above. The surrounding containment wall is 4 feet in height.

Two tank farm manifolds (piping connections) are provided on the south side of the tank farm, external to the tank farm containment area and within its own containment system. One is located on the east side, approximately midway between Tanks 80-9 and 80-12. The other is located on the west, approximately midway between Tanks 80-3 and 80-6. The manifolds connect loading piping from other locations to piping systems serving the individual tanks (referred to as transverse piping). Transverse piping to Tanks 80-1 through 80-6 runs north-south between the Tank 80-1 through 80-3 group and the Tank 80-4 through 80-6 group. The transverse piping serving Tanks 80-7 through 80-12 runs north-south between the groups formed by Tanks 80-7 through 80-9 and Tanks 80-10 through 80-12. The transverse piping for Tanks 80-13 through 80-15 runs north- south between the Tank 80-10 through 80-12 group and Tank 80-13 through 80-15 group.

There are multiple configurations for how liquids can reach the transverse piping [ITC Drawings, various dates]. The primary method is via either, or in some cases both, of the manifolds identified above. However, there are several tanks, including Tank 80-8, that have delivery piping from nearby train or truck loading/unloading racks. Others have connections to additional manifolds, such as those in adjoining tank farms or at the dock facilities. For the purposes of this evaluation, the details of those connections are not as important as the fact that there are additional piping systems and processes present within the containment area. Since those piping systems may have liquid quantities ranging from full to residual, failure of the systems can add fuel to fires or can create pathways for fluid flow that might not be typically assumed within tank farms.

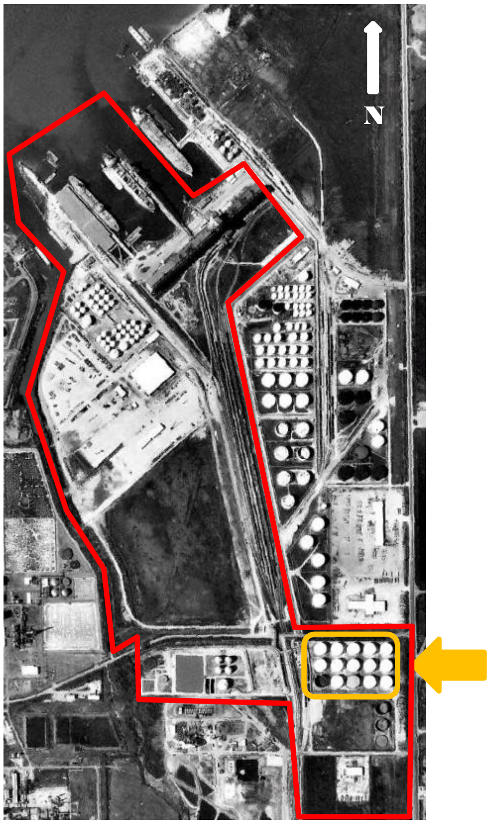

Figure 4: ITC Deer Park, Texas Facility with "First and Second 80's" Tank Farm Highlighted (Imagery Date: December 1978) [Source: Texas General Land Office via Google Earth Pro]

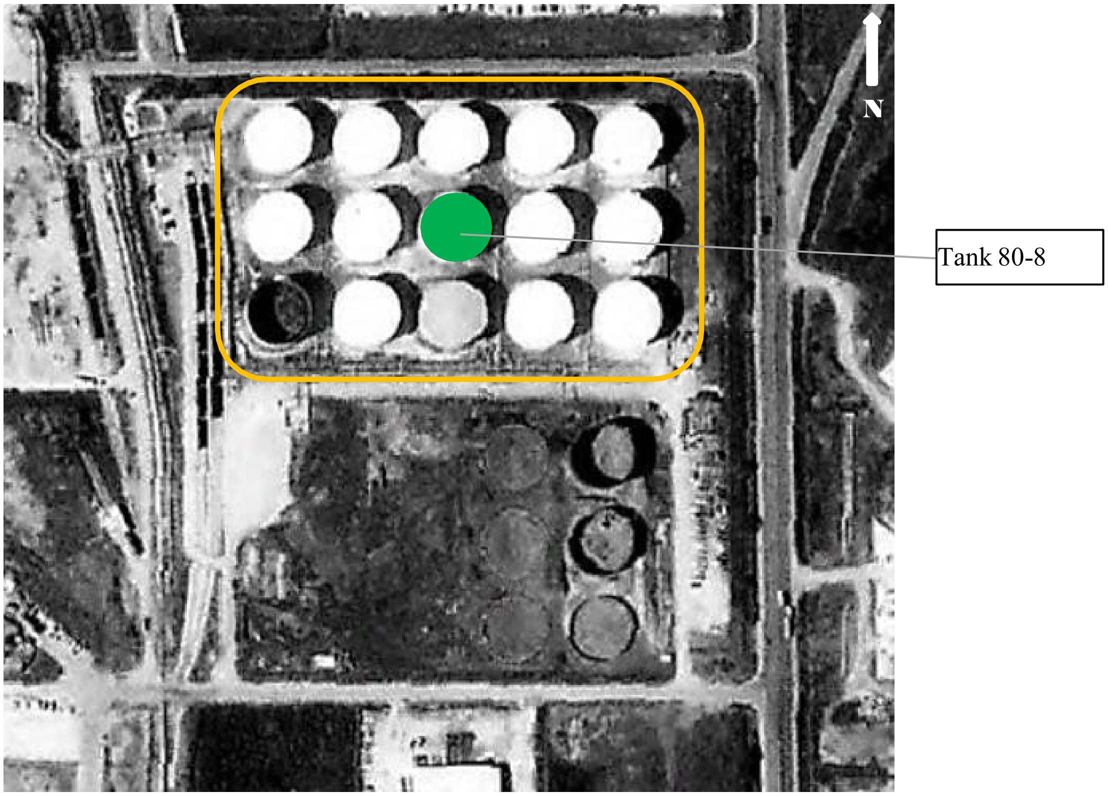

Figure 5: "First and Second 80's Tank Farm"
(Imagery Date: December 1978) [Source: Texas General Land Office via Google Earth Pro]
(Tank 80-8 highlighted in green.)

With the exception of Tanks 80-9, 80-11, 80-12 and 80-13, a pump system is provided at the base of the tank [ITC Drawings, various dates]. In general, the pump systems are either for filling/emptying of the tanks or to allow mixing within the tank. The Tank 80-8 system also allowed for blending of liquids delivered from various loading racks.

Drainage for chemicals within the tank farm is provided by a system of inlets placed between each of the fuel tank groups, with the piping between the outlets generally following the transverse piping described in the previous paragraph [ITC Drawings, various dates]. Three additional inlets are provided at the northwest area of the farm, with the piping running north-south to the west of the Tank 80-1 through 80-3 group. Each of the laterals are connected along the south of the farm, with east-west piping and eight inlets spaced across the area. The drainage connects to a similar system of piping for the tank farm to the south for the drainage piping transfers out of the area.

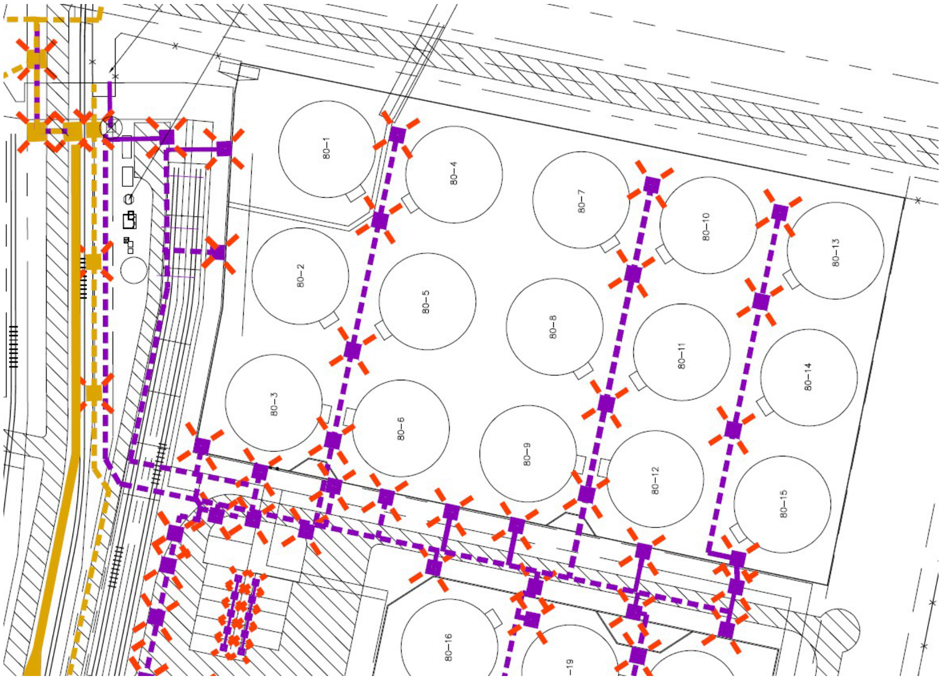

Figure 6: Drainage Arrangement
Purple Squares with Orange Arrows: Inlets; Purple Dotted Lines: Underground Piping [Source: ITC Deer Park]

With respect to fire protection systems, there are multiple layers present [ITC Drawings, various dates; CSB Interview with ITC Vice President of Safety, Health, Environmental, Security, Regulatory Compliance and Operations (VP of Safety), 2019b]. Each of the tanks is provided with an installed foam fire suppression system, which is manually supplied and operated. The supply connections for the systems are located along the south containment wall, outside the containment wall. Hydrants and monitors (see definitions), the majority being combination units, are located around the perimeter of the tank farm. Additional monitors are provided between the Tank 80-1 through 80-3 and Tank 80-4 through 80-6 groups, with three monitors installed to spray water on surfaces that are otherwise difficult to access. A similar line is provided in the segment between the Tank 80-7 through 80-9 and Tank 80-10 through 80-12 groups. Water-spray systems were also installed on the tank farm manifold systems. These water-spray systems could also flow foam and required manual activation. The activation points for these systems is also on the exterior of the south containment wall. See Figure 7.

The fire systems and emergency response apparatus are supported by four fire pumps (numbered 1, 5, 6 and 7). All of the pumps are located at the north end of the facility, taking water from the ship channel. See Figure 8 for general location of all pumps.

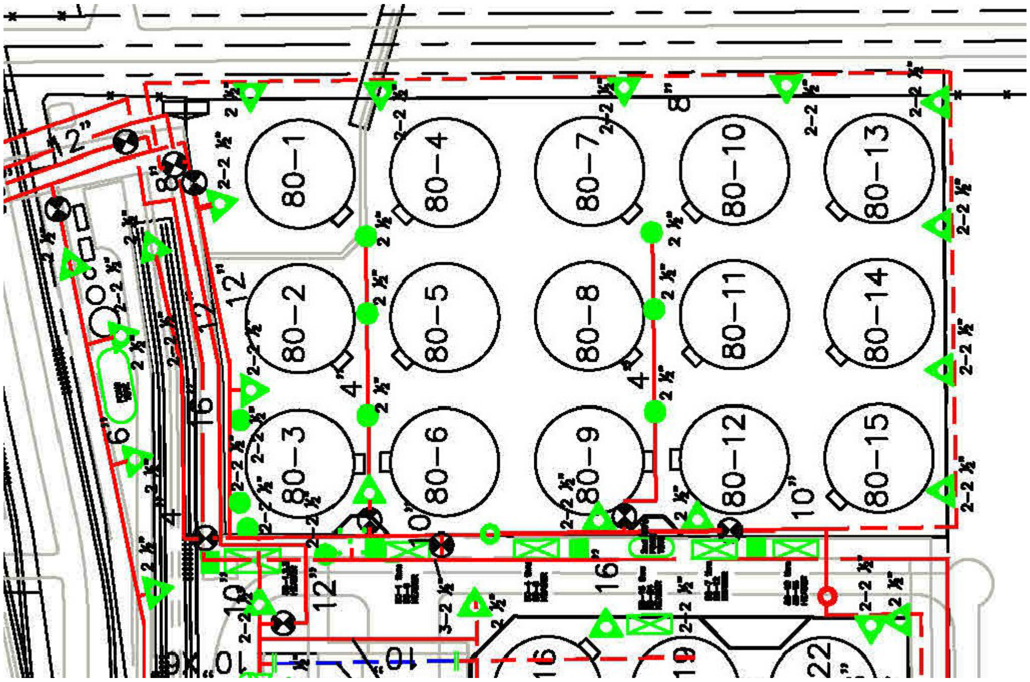

Figure 7: Fire Equipment Layout
Green Circles: Hydrants; Green Triangle with Circle: Hydrant with Monitor Attached; Green Rectangles and Ovals: Fixed Foam System Equipment; Red Lines: Water Piping
[Source: ITC Deer Park Facility Drawings]

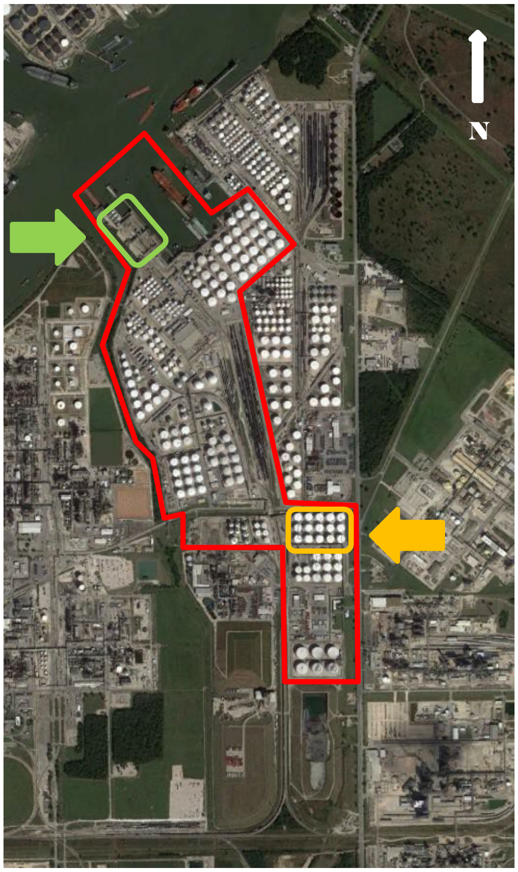

Figure 8: "First and Second 80's" Tank Farm (Yellow) and Location of Fire Pumps (Green) Highlighted (Imagery Date: October 28, 2017) [Source: Google Earth Pro]

For vehicle-based emergency response, access is provided into the tank farm at the southeast corner, entering from a bump-out/turnaround in the road running south from the tank farm to that gate off Independence Parkway. Another access is provided at the northwest corner, allowing access from the area south of Tidal Road, near the rail loading equipment. Once inside the tank farm, there is available space for vehicles to access much of the area, except those areas described earlier where transverse piping, manifold equipment and drainage inlets are present.

4.0 General Approach to Tank Farm Fire Protection

To gain a better understanding of how the ITC "First and Second 80's" tank farm fire protection approach contributed to the March 2019 fire event, one must understand the various components to the approach and how they either overlap one another or become redundant to one another. As well, it is important to understand the underlying basis for the various recommended approaches.

In the broadest sense, the fire protection approach for a tank farm incorporates preventative, monitoring, mitigative and responsive elements. Each of the elements is intended to assist in controlling certain aspects of fire initiation and progression, with the overall goal of not having fires in the first place, keeping them small when possible and preventing large-scale spread of fire if those measures fail.

The approach to tank farm fire protection follows the general process safety model that has been in existence for over a century. It should be recognized that today's process safety methodology has much of its roots in the 1970s, with the rise of the Clean Air Act and Clean Water Act. However, similar approaches were used in the industry prior to that, generally dating to the mid- to late-1950s [American Insurance Association, 1968]. This approach is evident in the industry's most-often used fire protection standards for the design tank farms, documents such as NFPA 30, *Flammable and Combustible Liquids Code*; FM Global Loss Prevention Data Sheet (FM LPDS) 7-88, *Outdoor Ignitable Liquid Storage Tanks*; and American Petroleum Institute (API) Recommended Practice (RP) 2021, *Management of Atmospheric Tank Fires*.

Each of these industry standards and guidance documents describes the process safety approach to different degrees. For example, NFPA 30 provides the least amount of description, taking a very prescriptive approach and providing relatively minimal detail via supplementary information in annex and handbook text. On the opposite end of the spectrum, API RP 2021 provides significant explanation and detail for each of the elements for consideration, allowing operators to better assess which elements they would like to favor over others. FM LPDS 7-88 rests between these two documents, perhaps skewing closer to NFPA 30 than API RP 2021. FM LPDS 7-88 is ostensibly a prescriptive document, but provides supportive information for its recommendations that recognize a risk model that addresses issues not considered by NFPA 30.

There are, of course, other standards available around the world, ranging from locally or nationally developed codes to industry-specific insurance guidelines. It should be recognized, however, that the majority of these stem from a fairly limited set of source documents. For much of the first half of the 20th Century, the National Fire Protection Association worked closely with the various insurance agencies present during the period to develop many of their standards [NFPA History, 2020]. Among the most significant contributors in the field of flammable and combustible liquids was the Factory Mutual Insurance Companies, which is a primary predecessor to today's FM Global [FM Global History, 2020]. Those two entities, along with the National Board of Fire Underwriters (today's American Insurance Association), were intrinsic to the development of what would become NFPA 30 and continue to be key players in its current development.

The American Petroleum Institute (API), which was founded in 1919, began developing safety standards soon after its establishment as part of its relationship with the insurance industry [API History, 2020]. Industrial insurers had been pushing for standard safety practices to bring crude oil and chemical production into line with other business sectors, and the API worked with them accordingly. NFPA 30 had been first published in 1913, with assistance and input from the insurance and petroleum industry [Benedetti and Shapiro, 2018; NFPA 30, 2018]. From 1917 to 1957, it had been developed as an ordinance for adoption by local entities, but after 1957 it was developed into the standard that exists today. In the period that it was an ordinance, NFPA 30 relied heavily on the standards developed by API. Since 1957, the API was regularly involved in the development process for NFPA 30 and their documents continued to be referenced within the standard. When API RP 2021 was developed, the API obtained assistance from NFPA and various insurance agencies to ensure continuity of that relationship. It is no surprise, therefore, that API RP 2021 heavily references NFPA documents in its recommendations and justifications.

While NFPA 30, FM LPDS 7-88 and API RP 2021 diverge somewhat in their specific recommendations, based on their respective intents, the general framework is the same. Of particular note is that all of these standards are developed around probabilistically likely situations, as opposed to worst-case conditions. As such, a single fire location (for example, tank liquid surface, spill fire, etc) is assumed, and the size of fires, other than those on tank liquid surface, is based on industry-accepted failure probabilities (such as limited size openings in piping systems, failures of pump or valve packings, small areas of tanks corroding, etc) [Benedetti and Shapiro, 2018; API RP 2021, 2015].

The elements for tanks fire protection can be categorized as follows. Each of the industry standards and guidance documents noted contains a mix of these elements. However, it should be noted that the mix differs depending on the intent of the document (see Sections 5.1 through 5.4 for more information).

- Preventative measures
    - Materials and methods of construction – Aid in preventing loss of system containment. These focus on the tank itself, as well as piping and equipment that might be associated with or attached to the tank. Issues here include compatibility with fluids handled, corrosion conditions, integrity of joints, operation condition ratings (such as pressure, flow rate, temperature, etc) and reliability of equipment for pressure boundary conditions. Incorporated into these considerations are the resistance of items to environmental conditions, including loads from wind, precipitation, seismic, standing water and similar natural phenomena. Items such as insulation material are generally chosen with respect to ignition and flame spread resistance.
    - Ignition control – Aids in preventing ignition should a flammable liquid spill occur. This category includes electrical classification, static control, lightning protection and stray/induced voltage elimination. It can also include administrative controls such as those associated with smoking, hot work, hot surfaces (including on vehicles) and portable equipment.
    - Oxidant control approaches – In many cases, the vapors in the empty space between a liquid and a roof will be at concentrations above the upper flammable limit. In cases where the air-vapor mixture could be within the flammable range, the mixture can be augmented either with additional vapor so that the vapor concentration is raised above the upper flammable limit or with an inert gas, such as nitrogen or carbon dioxide, do that the available oxygen is reduced below the concentration needed for sustained flame development.
    - Process controls – With respect to fire protection, process controls are generally used to ensure system conditions remain within the design parameters for the piping, equipment, and tanks. Those parameters are generally pressure related, but they could also be related to temperature, flow rate, reaction time or other aspects. Process controls can be performed manually or via automatic control systems.
    - Precipitation drainage – Although nominally an environmental control, precipitation drainage is advantageous to fire prevention in that it aids in minimizing corrosion concerns and reducing excess forces on various items. It is also helpful in eliminating obstructions that might preclude performing needed corrective work in the area, such as standing water, ice development and presence of animals.

  - Mechanical damage control – Tanks, piping and equipment can be subject to mechanical damage for various reasons, with the most typical being vehicles. Engineered and administrative controls of various types can be employed, depending on what the expected hazards are.

- Monitoring measures
  - Process monitoring – Process monitoring tends to be a more passive approach to process controls. In these cases, the monitors may be the same as those for process controls, but rather than prompting an automatic or manual control they simply alert an operator to take some type of action. That action may or may not be pre-defined. Process monitoring could be as simple as visual observance during a process, or it could a sophisticated electronic system.
  - Adverse condition monitoring – Detection and alarm devices can be placed within the operating environment, either within the process/storage equipment or in the surrounding area, to detect conditions that represent releases in unexpected ways. This includes high- or low-pressure sensors, level sensors, leak detection, flammable vapor/gas detection and similar equipment.
  - Inspection, testing and maintenance – The administrative control of ongoing inspection, testing and maintenance is considered a monitoring measure because it validates integrity and functionality of systems and equipment. The program can identify individual issues with various items and can be used to track and trend multiple items to determine if a systemic issue exists.

- Mitigative measures
  - Facility siting – The location of a tank farm relative to its surroundings is considered a mitigative measure in that proper siting allow for reduced radiant exposure and impacts of other fire effects to other locations while emergency forces response. Within most standards, such locations specifically include structures on adjoining property, roadways adjoining the tank, important buildings on the same property and egress points both on and off the property. Other locations, such as other tank farms, rail lines, other operations on the same or adjoining properties and similar locations are addressed in a limited number of standards, but are often considered in evaluations.
  - Tank-to-tank spacing – Tank-to-tank spacing is similar to facility siting, but is intended to reduce radiant energy and other fire effects from one tank to another, even if within the same containment area. As well, the spacing is meant to address small spill fires or limited jet flames from pipe breaches. The tank spacing is also intended to allow space for emergency response operations.
  - Tank, piping and equipment design – Tanks are provided with vents of various types. In a passive mode, the vents allow vapor release, which aids in process control and mitigation of overpressure conditions. In a fire condition, venting of vapors is typically needed to avoid over-pressurization of the tank. Fluid overfill vents are also provided to ensure a tank cannot be filled with too much liquid. The design of piping and equipment often takes into account fire failure criteria, as well as providing pressure relief vents, elements that fail to a safe condition upon fire exposure or similar safety features.
  - Small spill control – Similar to precipitation control, elimination of small spills eliminates the immediate hazard posed by a flammable or combustible liquid, but also minimizes long term exposures to systems and equipment. This type of control can be localized, such as small containment walls (berms or dikes), and require manual intervention to correct or they may be a larger drainage system that removes spill to a collection or treatment system elsewhere.
  - Large spill control – Tank farms typically employ containment wall or barriers at the perimeter of the tank farm to control large spills. The containment is are typically sized to accommodate the largest tank within the containment plus certain amounts of precipitation. Where containment walls are impractical, a drainage and separate containment system might be used.

  - Vapor reduction systems – Some tank farms employ vapor reduction systems. Several common system types use firefighting foams or similar foams to coat the surface of a spill. Other materials are known to be used, depending on the fluid stored or used.

  - Active fire protection systems – A variety of fire protection systems can be installed within tank farms, including fixed foam systems for the tanks themselves, fixed exposure protection systems either on the tank or in the general vicinity of the tanks (via monitor nozzles, water spray systems, etc), fire detection systems that initiate process controls and equipment to support manual intervention. The type of fire protection equipment chosen for a given installation is generally chosen in balance with other preventative and mitigative measures (based on spread or exposure hazards to surrounding elements), as well as in consideration of responsive measures.

  - Passive fire protection systems – Passive fire protection includes both physical features that obstruct radiant energy or direct flame exposures, such as fire barriers or natural features (hillsides, for example) or physical separation that reduces those exposures to acceptable levels. The latter is most often used, with prescribed distances between tanks included in international standards.

  - Process controls – Process controls can be designed to aid in mitigating accidents by controlling fluid flow (such as eliminating delivery, venting to reduce pressure, moving of liquids to other vessels or tanks outside the accident area and other actions. Use of such controls can be manual or automated, but the methods vary considerably.

- Responsive measures

  - Active fire protection systems – Although the intent of active fire protection systems is typically to control fires and limit their spread, some events extend beyond the area of origin and require greater response. Installed fire systems will aid with these responses. Fire pumps, water supply systems, hydrants, monitors, fire department connections, foam connection points and other equipment fall into this category. It should be made clear, however, that the design of these systems must be considered in concert with the response agencies discussed below.

  - On-site emergency response agency – On-site emergency response consists of personnel and equipment dedicated to the site, often employed or directly contracted by the company that owns or operates the site. Personnel are trained in the hazards for the facility, with the apparatus and equipment matching the operations intended by the personnel. This can include any organized effort ranging from individuals that respond to small events such as spills or incipient fires to a dedicated organization such as a fire brigade or fire department.

  - Municipal emergency response agencies – Most tank farms are located in areas where a community fire and emergency response organization are present. This is typically some type of local fire department but can include more extensive services depending on the area. The experience and capabilities of such organizations, with respect to tank farm fires, varies considerably.

  - Mutual aid associations – In locations where multiple industrial facilities are located, shared resources through mutual aid associations is a common approach. These associations can combine any number of response agencies, and can include support from local industry, municipal response organizations, other governmental agencies (such as the US Coast Guard in areas with waterways) and established suppliers for materials and equipment. They may also involve non-traditional responders, such as heavy equipment operators, piping system operators and electrical system technicians and others. The experience and capabilities of the overall organization is highly dependent on that of each individual organization and the working relationships within the association.

  - Private emergency response contractors – Large industrial fires, particularly those that involve probabilistically unlikely events, can exceed the capabilities of the agencies identified above. There are a range of private companies, each with their own range of capabilities, that can be contracted to assist or take over the response. Some facilities will have such companies on an as-needed contract, while others will contract services when the need arises.

The extent to which each of these measures, particularly the responsive measures, is implemented varies among tank farms. The majority of the preventative, monitoring and mitigative measures are prescribed by industry standards, but some allow for judicious application. Features such as ignition controls, small- and large-spill control and materials and methods of construction have detailed recommendations that make them common approaches across industry. Features such as facility siting, passive fire protection systems, active fire protection systems and emergency response agencies are inter-related and the standards require such features at a generic level, but do not clearly define how such features must be implemented and how they should overlap. Detailed recommendations are available for some of those features once such systems are incorporated into a facility, such as NFPA standards for the design of fire suppression or fire detection systems. Similarly, there are few recommendations as to when an on-site emergency response agency should be provided, or what the capabilities of that agency should be, but there are national and local standards pertaining to personnel training, protective equipment, motorized apparatus, firefighting equipment, and other aspects of the agency once it is established.

The lack of prescriptive requirements for these aspects of tank farm fire protection often make it difficult for those unfamiliar with the balance of risks to determine how well a facility might be protected or how impactive a feature, or lack thereof, might be to an emergency situation. Even for those with a detailed familiarity with the various features and their risk implications, it is sometimes difficult to judge the impact a given feature may have overall. Because of that, within the context of this report, the opinions of potential lessons learned are based on the experience and opinions of the author, and it should be recognized those perspectives can be debated.

5.0 Engineering, Process Safety and Risk Management Considerations

Many aspects of the fire protection of tank farms are driven by regulatory requirements, such as adopted codes and standards within a local jurisdiction, national regulations for pollution control and laws regarding safety. Since at least the mid-1960s, local and/or state governments have had a direct hand in reviewing and permitting tank farms, both from a construction standpoint and a continued operation perspective.

As noted previously, available information from the tanks and original permits put tank construction between 1976 and 1978. If one accounts for typical industry timelines, obviously adjusted for the information technology methods of the mid-1970s, for civil engineering surveys, soil sampling for structural considerations, engineering and design, permit application and approval, procurement of tank construction services and scheduling and mobilization for construction, it is likely that engineering design would have occurred in the latter part of 1975 or the early portion of 1976.

An attempt was made to determine what agencies may have had a hand in reviewing and permitting the tank farm based on that assumption for the beginning date of facility design. Admittedly, this was a difficult undertaking given the length of time that has elapsed from original construction to the time of the fire. A request for original design plans and permitting information was made by the CSB, but ITC indicated that such information was not available. Therefore, information derived within this section is somewhat speculative and based on the data available.

It is clear, based on permits provided by ITC to CSB, that the Texas Air Control Board issued construction and operational permits for the “First and Second 80’s” tank farm. What is unclear from a historical standpoint is what regulations, codes, standards, or other criteria were used as the foundation for the permits. The available histories of the Texas Air Control Board suggest the organization had a broader span of control during the 1970s than it has now, and could have had oversight of fire protection issues as part of its role as a regulator of pollution control concerns [TCEQ History, 2020]. However, legacy documents are unclear.

Other Texas state organizations that oversee crude oil and chemical operations, such as the Texas Railroad Commission, were found to not have oversight of the facility, as the extent of their responsibilities terminated at the site boundary.

Available information for the Harris County Fire Marshal's Office, which was established in 1974, and the Deer Park Volunteer Fire Department Fire Marshal's Office, which also appears to have been founded in the early 1970s, suggests that those organizations had not yet matured to a point of reviewing and permitting the industrial facilities within the jurisdiction [Zelade, 2011]. The Texas State Fire Marshal's Office was established as a standalone entity in 1975, but it existed as far back as 1910 under other the Commission of Insurance and its predecessors. Various histories suggest the State Fire Marshal's Office could have had review and permit authority, but no confirmation of this fact could be obtained.

At about the same time, national regulations were coming into play via the Occupational Safety and Health Administration. Code of Federal Regulations, Title 29, Part 1910 (29 CFR 1910) saw its first publication in 1974 and required compliance to NFPA 30 in its Subpart 106 series pertaining to flammable and combustible liquids [39 FR 9957]. Given this, there would have been a national regulatory obligation to utilize NFPA 30 and related codes and standards, regardless of the enforcement structure within the State of Texas. See Section 5.3 for more discussion on 29 CFR 1910 issues.

Outside the regulatory structure, but within the realm of good engineering and risk management practice, were a wide range of documents that could have informed the original design of the facility and supported continued operations. API RP 2021 has an original publication date of November 1974, but issues with printing delayed its public release until sometime in early 1975 [NFPA, 1975]. Therefore, it would have been newly available at approximately the time of design engineering for the site.

Although FM LPDS 7-88 wasn't published yet in its current form, the predecessor of FM Global did make its recommendations available via the *Handbook of Industrial Loss Prevention*, which had been published since 1959 and contained an entire section on flammable and combustible liquids storage [Factory Mutual, 1967]. Other documents, such as the *Hazard Survey of the Chemical and Allied Industries* pamphlet prepared by the American Insurance Association, first published in 1968, outlined the interactivity of process and fire safety [American Insurance Association, 1968]. The *Fire Protection Handbook*, published by NFPA, was also available and contained explanatory information to support NFPA 30 and general industry practices for fire protection in the process industry [NFPA, 1969]. These documents and others were available at the time of design and construction, and have continued to be available for emergency response and risk evaluation.

5.1 NFPA 30 CONSIDERATIONS

As noted above, the assumed approximate date for design is late 1975. The 1976 Edition of NFPA 30 wasn't approved until November of that year and was published in early 1977. Given that, the previous edition, 1973, would have been available for design and regulatory enforcement. That version of the standard was used to evaluate the original design. It should be noted, however, that the evaluation is limited to large-scope items, based on the available information, that could have influenced the fire event, and should not be considered an in-depth analysis of all aspects of the design.

Of obvious importance to the basic question of fire spread are spacing requirements (for example, from tank-to-tank, from tanks to adjoining buildings, from tanks to other process equipment, etc). It should be recognized from the outset that the spacing requirements in NFPA 30 are derived from the experience and data collected by committee members and the general industry. The following is taken from commentary in the *Flammable and Combustible Liquids Code Handbook* (2018 Edition) for Section 22.4.1 of NFPA 30 (2018 Edition) [Benedetti and Shapiro, 2018]:

The separation distances specified in the tables were developed through evaluation of storage tank fire incidents over the 70 or more years since this Code was first conceived. The minimum distances *to adjoining property and between adjacent tanks…have occasionally been decreased over the years as the mechanism of fire spread has become better understood through experiment and experience.*

Although not clearly stated in this or other texts on the subject, an underlying assumption for the safe spacing of tanks is eventual emergency response and application of firefighting water or foam. As well, the spacing is meant to address radiant exposures from small ground fires that will be suppressed quickly by responders. Larger ground fires, particularly ones that expose adjoining tanks directly, are not assumed within the tank spacing requirements.

While the various texts recognize that fires may burn for some extended period, there is no stated objective that the proscribed spacings will definitively preclude ignition or damage of adjoining tanks or structures without some type of intervention. The premise that firefighting intervention will occur is based on the same loss records cited by the paragraph above, in that few of the incidents that are considered by the committee don't involve direct firefighting for the tank fire or exposure protection for surrounding structures. This is mentioned, though not explicitly stated, in the commentary in the *Flammable and Combustible Liquids Code Handbook* (2018 Edition) for Section 22.4.1 of NFPA 30 (2018 Edition):

Protection. *In all three tank categories, distinction is made between the presence or absence of protection for exposures, as defined in 3.3.46 and explained in more detail in this commentary. The intent is that, if fire should occur in the tank, some fire-fighting capability will be available to prevent fire spread to the adjacent property. The fire in the tank is assumed to safely burn out, and no attempt will be made to extinguish it.*

NFPA 30 (1973 Edition), Section 2031 required aboveground tanks operating at near-atmospheric conditions to be constructed in accordance with any one of a number of industry standards, dependent on the type of tank and the fluid to be stored. Among the referenced standards are those from Underwriters Laboratories and the American Petroleum Institute. Without specific design specifications or drawings, one cannot be certain that the tanks were built to one of the noted standards, but given that similar requirements are present in NFPA 30 dating to the 1957 Edition and that the standards noted in Section 2031 had been published since at least the early 1960s, one could safety assume that compliance to basic construction was achieved. Those same standards include requirements for standard and emergency vents, which are called for in Sections 2140 and 2150. Those features are assumed to have been provided.

With respect to location and spacing, there are several applicable requirements. Section 2110 requires all aboveground vertical tanks containing stable flammable and combustible liquids (other than Class IIIB), operating below 2.5 psig and not containing liquids with boil-over characteristics, which would include all the tanks and permitted liquids in this tank farm, to comply with Table II-1 for spacing to property lines, for protection on neighboring lands, and to important buildings on the same property, for control of fire spread to a single owner's property. The required distance to a property line is one-half the tank diameter or 90 feet, whichever is less, for tanks with installed fire protection, and a full tank diameter for tanks without such a system. Input from ITC personnel suggests that the fire protection systems were present at installation of the tanks, so the protected tank requirements can be used. Therefore, the specified distance would have been 55 feet, based on tank diameters of 110 feet. For structures on the same property, the allowable distance is either one-sixth the diameter or 30 feet, whichever is less. Again, for a tank with a diameter of 110 ft, the allowable distance would be approximately 18.4 feet. As can be observed in Figures 1 through 4 above, these distances are easily met for the structures present at the time of installation.

For shell-to-shell spacing, Section 2121 would have been applicable. It identifies the required shell-to-shell spacing to be one-sixth the diameters of the two adjacent tanks. As with the above spacing, this criterion is based on tanks containing Class I through Class III liquids that are stable and not prone to boil-over and the tanks are operating at less than 2.5 psig. For this case, the required spacing would be one-sixth of 220 feet, which is approximately 36.7 ft. Measurements taken from available drawings and aerial photographs suggest distances between 35 and 37 ft. Therefore, it is assumed the tanks met their required spacing when installed.

Of note, however, is Section 2125, which stated "When tanks are in a diked [containment] area containing Class I or Class II liquids, or in the drainage path of Class I or Class II liquids, and are compacted in three or more rows or in an irregular pattern, greater spacing or other means may be required by the authority having jurisdiction to make inside tanks accessible for fire fighting purposes." Additional spacing does not appear to have been provided in this case, but attempts to address the concern appear to have been made by providing firefighting monitor nozzles within selected areas. The nozzles would assist in providing cooling water to the tank faces that are otherwise obstructed when at the perimeter of the tank group. This would address the intent of the NFPA 30 requirement, although there is no clear information as to whether

Section 2170 identified requirements for containment. Containment walls are not specifically required, but they were the primary means employed for containment (and remain so today). Section 2172 identifies that the containment must be sized to accommodate the volume of the largest tank, with consideration of any other tanks or large equipment within the containment accounted for. The tanks are sized for 80,000 barrels, which equates to 3,360,000 gallons (assuming a barrel volume of 42 gallons) or 449,138 cubic feet. As noted earlier, the containment inner dimensions are approximately 449 feet by 732 feet, resulting in a horizontal area of 328,668 square feet. Each tank, assuming a 110 feet outer diameter, would occupy a horizontal area of 9,503 square feet. Subtracting the area of 14 of the tanks in the farm (since the failed tank is being considered) from the total area gives 195,626 square feet. Dividing 449,138 cubic feet (needed volume) by 195,626 square feet (available area) results in a needed depth of approximately 2.3 feet. The containment walls at the facility are 4 feet tall, providing ample additional volume for local precipitation, additional equipment, vehicle ramps and other items that might affect volume.

Section 2173 has additional requirements for the construction of containment walls that cannot be fully evaluated due to a lack of design drawings and potential modification over time. Other features, however, can be examined. Section 2173(g) required that subdivisions be provided for any containment containing two of more tanks. Those subdivisions could be drainage channels or intermediate containment walls. The drainage between the tanks within the containment area as described earlier (see latter paragraphs of Section 3.0) does not appear to conform with Section 2173(g)(2), which covers tanks in excess of 100,000 gallons and states:

(2) When storing normally stable flammable or combustible liquids in tanks not covered in sub- paragraph (1), one sub-division for each tank in excess of 100,000 gallons (2,500 bbls.) and one sub- division for each group of tanks (no tank exceeding 100,000 gallons capacity) having an aggregate capacity not exceeding 150,000 gallons (3,570 bbls.).

The drainage as provided segregates the tank farm into groups of three tanks each, while Section 2173(g)(2) would have required the drainage to be provided such that each tank was separated from adjoining tanks. Section 2173 allows for the use of intermediate containment walls to either replace drainage or augment drainage, however no intermediate containment walls are provided. The sloping and draining across the entire tank area, evidenced by a general slope from the north to south direction and additional drains at the south side of the farm, may have been provided to offset the lack of inlets between tanks. In theory, the slope would move any spilled liquids away from the immediate tank of concern and transfer the liquids to the drainage system at the south side. As an alternative approach, the provided condition doesn't satisfy the intent of the requirements in Section 2713(g)(2).

Section 6710 on fire control required the provision of small hose systems and fire extinguishers for initial fire control, but is relatively limited for large-scale fire control measures. The section, in its entirety, reads:

6710. Suitable fire-control devices, such as small hose or portable fire extinguishers, shall be available to locations where fires are likely to occur. Additional fire-control equipment may be required where a tank of more than 50,000 gallons individual capacity contains Class I liquids and where an unusual exposure hazard exists from surrounding property. Such additional fire-control equipment shall be sufficient to extinguish a fire in the largest tank. The design and amount of such equipment shall be in accordance with approved engineering standards.

The spacing requirements noted above are for protected tanks, so it can be assumed that the tank-mounted foam fire suppression systems were installed at the time of tank design and construction. The provided monitors at the perimeter of the tank farm were a typical approach for manual tank fire suppression and exposure control. The intermediate line of monitor nozzles, installed within the tank farm as described earlier, are a somewhat unusual approach, in that they would require responders to enter the tank farm enclosure.
They appear, however, to have been installed to, as a minimum, provide exposure protection for tank surfaces that would be inaccessible from the perimeter monitors. Providing monitors to achieve the general goal of tank cooling is common and accepted, but placing them between tanks and within the containment area is

In the 1973 Edition of NFPA 30, insulation on tanks was considered relative to vent sizing requirements, but was not included in tank separation distance requirements. There were no specific requirements regarding combustibility, flame spread or other fire-related characteristics, but Section 2157 did require insulation to remain in place during fire exposures, to not be dislodged by hose streams and to have a thermal conductance value of at least 4 British thermal units (Btu) per hour per square foot (Btu/hr-ft^2) if it were to be accounted for in certain ways for venting calculations.

There were no restrictions to performing firefighting operations within the containment area of tanks, though NFPA 30 discouraged it via general information in the Appendix. If such operations were present, they needed to be performed in accordance with other requirements in NFPA 30 (for handling, process, etc) and had to be controlled for ignition prevention and hazard exposure to the tanks.

Given the information above, the tank farm can be said to have been largely designed following the general parameters of the 1973 Edition of NFPA 30. However, there are some issues that complicate ground fire scenarios such as the one being evaluated herein. The overall drainage system is problematic in several ways.

One is that such drainage systems were not required to be designed for large-scale spills, and in this case resulted in the drains being inadequate to move liquids quickly from the area. Even if the system had been sized for such a large spill, the inlets were positioned along the same pathway as the transverse piping and the general slope of the tank farm overall would have moved the liquid toward pipeline systems, particularly the transverse piping racks and the manifolds at the south side. As a result, a "running fire" (i.e., one that tracked with the spill) would expose other tanks and piping before entering the drainage system. That appears to have been at least partially the case in this particular fire.

A second concern is that the movement of the fire toward the south, due to the drainage, prevented safe access to the fire system valves and foam connections located along that south wall. Those same safety reasons would be applicable to placing personnel at monitor nozzles or locating fire apparatus and personnel in this area.

That same slope likely also contributed to some of the initial tank exposures and can explain some of the fire progression. Burning liquids that were on the ground during the initial and subsequent releases would have followed the slopes toward the inlets to the east of Tank 80-8 and the general slope moving south toward Tanks 80-9 and 80-12, likely had some contribution to thermal exposure to those tanks as the liquid moved closer or past the tanks on their way toward drainage points. The southward movement would have continued as the drainage piping became overwhelmed, partially explaining the greater range of fire spread and damage on the south side of the tank farm than at the northern section.

With regard to subsequent changes in NFPA 30 since the time of design, the requirements for tank styles and material choices, construction standards, tank spacing (both shell-to-shell and to other locations), piping systems, and venting have not significantly changed in current editions. As well, the general requirements for drainage and containment have not changed considerably since that time, although there are some changes to the details of various components of the design. Placement of process equipment within the tank farm remains permissible, with newer editions (since the 2012 Edition) requiring a closer examination of such operations and their hazard exposure to the tanks.

On the whole, the tank farm could be configured largely similar to its original design if it were built more recently, if only NFPA 30 inputs are considered. It should also be noted that NFPA 30 does not retroactively apply (see Section 1.4 of more recent editions), so current requirements, even if they did diverge from the historic requirements, wouldn't have been applied to the tank farm as a matter of compliance to local codes. See the remainder of Section 5.0 for potential applicability of newer requirements under other compliance structures.

5.2 API RP 2021 CONSIDERATIONS

API RP 2021 is, as its title implies, a recommended practice. Like any code or standard, it does not on its own carry any legal authority unless specifically invoked by some law, regulation, or other legally-binding reference. Even if mentioned, any referencing legislation would have to adapt much of the language in API RP 2021 from "should" language to "shall" or "must" statements to require compliance.

At the time of design and construction of the ITC Deer Park "First and Second 80's" tank farm, it is unlikely that API RP 2021 was adopted by any jurisdictional authority having oversight of the facility. Although the document was released during the first quarter of 1975, the timing for adoption and implementation, which often takes three months to a year for most jurisdictions, would have overlapped the early design period of the facility. In such cases, engineering and development teams in all realms (i.e., industrial, commercial, residential, etc) typically request relief from the new standard, citing the cost and effort that has already been expended toward compliance to the existing regulations, codes and standards.

However, if one assumes the design team for the facility had the document available to them, its contents would be a bit of a conundrum in this particular case. API RP 2021 (known in its early versions as Publication 2021) couches its discussions on strategies, tactics and use of installed systems on the foundation that an established emergency response organization exists (either an onsite organization or a responding local fire department), the facility design is mature enough for that organization to evaluate against its capabilities (if the facility does not already exist) and a path forward for closing any gaps between response capabilities and facility design is established. At the time of construction of the tanks, it is not clear that an emergency response organization was in place or, if one was in place, that they were an integral part of the design of the facility as intended by API RP 2021.

Given these various perspectives, it would seem unlikely that API RP 2021 was implemented as part of the design effort for the "First and Second 80's" tank farm. The timing of the design and construction of the tank farm does not align well for the guidance document to have been adopted by the design team. Additionally, if it was taken up as design criteria, the timing of plant development and emergency response team founding and maturation also does not align well for obtaining detailed input for the design team.

Therefore, it would be more likely that the design team for the facility designed the fire protection based on existing industry practice of the day, and the emergency response team adapted to those conditions over time. See Chapter 6 on emergency response for more information.

5.3 WORKER SAFETY (29 CFR 1910) CONSIDERATIONS

When the "First and Second 80's" tank farm was constructed, 29 CFR 1910 was still a relatively new document. When the regulations were first published and became effective in 1974, they did not contain the requirements currently in 29 CFR 1910.119. Those requirements did not become part of the regulations until 1992 [57 FR 6403, 1992]. Therefore, the original installation and any pump or piping modifications made prior to May 26, 1992 (when the rule became effective), would not have been subject to the requirements [57 FR 6356]. After implementation of the rule, analysis of any modifications would likely have been assumed exempt from a process safety analysis based on the tank farm exception included in 29 CFR 1910.119(a)(1)(ii)(B).

The basic question, however, is whether or not the blending operations for Tank 80-8 constitutes a "process" that would be evaluated under the process safety management (PSM) standards. Means to fill and empty the tanks would, by necessity, seem to be included in the original scope of 29 CFR 1910.119(a)(1)(ii)(B). However, the introduction of blending and mixing operations for the tank does raise a question as to whether processing is performed within the tank farm.

The CSB asked exactly that question with regard to accidents in other facilities in its March 31, 2014, letter of comments and input to Occupational Safety and Health Administration (OSHA) Docket OSHA-2013-0020, which sought changes to the process safety management requirements in the same vein [CSB, 2014]. The extensive details of that letter will not be repeated here, but the CSB information provides ample reasoning to include blending and mixing in the scope of a process, and thus require application of PSM standards.

In its final decision, OSHA determined that tanks either connected directly to a process or involving a process are subject to the PSM guidance [OSHA 3903-03, 2017]. Hence, beginning in approximately mid-2016, the “First and Second 80’s” tank farm would have been no longer exempt from the PSM process. While it could be argued that only Tank 80-8 would be subject to the PSM process since it is the only tank performing blending, a broader reading would include the entire tank farm because of the lack of segregation of Tank 80-8 from the remainder of the tank farm and the interplay of various scenarios. Based on available information, PSM analysis of the tank farm had not yet been performed by the time of the fire, although management of change and pre-startup safety review was performed under the broader ITC safety structure [CSB Interview with ITC VP of Safety, 2019a].

Subsequent to the March 2019 fire event, OSHA cited ITC Deer Park for violation of the Process Safety Management Standard (29 CFR 1910.119), confirming the applicability of PSM to Tank 80-8, as a minimum. Once the PSM process was started, the implementation of recognized and generally accepted good engineering practices (RAGAGEP) would have been expected [OSHA, 2016]. RAGAGEP in this case would have minimally included more recent editions of NFPA 30 and API RP 2021 (see Sections 5.1 and 5.2), as well as modern equipment considerations (see Section 5.6).

Separate from the process safety management aspect are changes in safety related to emergency responders, both in general industrial fire brigades, with 29 CFR 1910.156 being introduced in 1980, and hazardous materials responders, with 29 CFR 1910.120 being implemented in 1996. The impact of those conditions will be more fully evaluated in Section 6.0 of this report.

5.4 INSURANCE CONSIDERATIONS

When the tank farm was being constructed, industrial insurance companies had a strong hand in influencing design. The insurance business was influential in developing NFPA 30 (see Section 5.1 above), and many insurers would utilize NFPA 30 as the foundation for their own guidelines or framework for determining risk and rates for their insureds. In the 1950s and 1960s, process safety management approaches generally followed the insurance guidelines because it was those organizations that had developed the needed risk-based information accepted as input to PSM, such as probabilities of events, effectiveness of engineered systems and success of certain approaches.

In the late 1960s, organizations like Factory Mutual (today’s FM Global), Factory Insurance Association (which later became Industrial Risk Insurers and today’s AXA XL), American Insurance Association (which survives today) and others began making their risk-management approaches more public, in an attempt to influence industry to accept better practices through process safety management, as opposed to it being imposed through the insurance process. As one example, Factory Mutual updated its *Handbook of Industrial Loss Prevention*, which had been first published in 1959, to the second edition in 1967 [Factory Mutual, 1967]. The second edition greatly expands upon the original and provides several pages on tank farm installations. In the early- to mid-1970s, Factory Mutual began expanding the *Handbook* and its associated support documents into its Loss Prevention Data Sheet library that exists today. The *Handbook* chapters on flammable and combustible liquids would encompass a range of data sheets, with much of the large storage tank information landing in Loss Prevention Data Sheet (FM LPDS) 7-88, *Storage Tanks for Flammable and Combustible Liquids* [FM LPDS 7- 88, 1976].

The approach to fire protection in the *Handbook* and the subsequent FM LPDS 7-88 focuses more on large fires that occur at ground level and expose the tanks. As a result, the FM approach leans more heavily on localized containment, smaller tank groups within a single containment, spacing that considers the edge of containment walls to exposed tanks and other structures and installed fire protection systems that can be operated reliably (and preferably automatically). Compared to NFPA 30, the FM approach better matches the multi-exposure concerns that arise for vessel or pipe failures, such as happened at the ITC Deer Park facility. It also tends to reflect the broader insurance approach that leans more on engineered controls as opposed to administrative controls and responses. It is for this reason that there is little to no discussion of emergency response or the recommended structure of emergency forces for tank farm fires contained in the *Handbook* and subsequent FM LPDS 7-88.

Tank farm fire protection standards in the insurance industry tend to range, depending on the rating and premium structure established by the particular insurance company, with NFPA 30 being the minimum expectation. Some companies, such as FM Global though its Loss Prevention Data Sheet program and AXA XL through its GAPS program, publish those standards for public use, while others hold them only for access by insureds and potential clients. Regardless of how companies make those standards available, it can be said that they represent improvements over NFPA 30 in many aspects regarding fire protection of tank farms.
However, it must be clear that these standards tend to assume fundamentally different risk levels, from one another and from NFPA 30. Using historic versions of today's insurance-based tank farm standards, it is evident that the insurance standards were not implemented as part of the design. The "First and Second 80's" tank farm does not follow the containment and spacing requirements contained in the guidance included in contemporary standards from Factory Mutual, the Factory Insurance Association or the American Insurance Association. Since the standards from these three organization formed the backbone of the remainder of the industry, standards from other insurers were also assumed to have not been applied.

How an insurance company views the various aspects of tank farm fire protection and considers them in the framework of their protection, particularly for situations where the insurance company wasn't included in the original design, isn't always as clear as the above might appear [references withheld due to confidentiality]. As previously noted, some companies view tank farm protection methods as eventually requiring manual intervention, which would conflict with their general perspectives of not giving significant credit to manual or administrative controls. With that perspective, those companies will more likely write off the tank farm rather than analyze it in detail to determine a more likely loss. That appears to be the case in three recent insurance surveys provided by ITC Deer Park to the CSB, one each from 2015, 2017 and 2018. The 2015 assessment mentions the tank farm only in context of maximum foreseeable losses (which assumes little to no manual intervention) and indicates an assumption that the "emergency response personnel (both site PEO [Plant Emergency Organization] and public agencies) act in accordance with existing plans." The 2017 report provides significant focus on a different tank farm with regard to potential loss factors, but assumes any given tank farm to be completely lost, obviating any discussion on effectiveness of installed systems or emergency responders. The 2018 survey provides significantly more detail about the various systems and the emergency response team, but the information does not link the various aspects of fire protection and assumes a maximum loss of a tank farm.

The above information isn't meant to be critical of the insurance business and their varied approaches to tank farms, but is intended to highlight the variety of approaches taken and the information often available from insurance providers. Given that broad band of data, it is incumbent upon facility owners and managers, and more specifically their risk management leaders, to understand what is being assumed by insurers and what data is available from their organizations. In the case of ITC Deer Park, it is evident that the input from these two insurance surveys did not necessarily support site personnel in understanding the specific risks within the tank farms, only the potential loss from a large-scale fire in a single tank farm.

5.5 CORPORATE RISK MANAGEMENT CONSIDERATIONS

The term “corporate risk management” has gained much attention since the inclusion of process safety management in regulatory guidelines. But, in matter of fact, the concept is more than a century old. With respect to fire protection, it dates to fires in mills and other industrial facilities in the late-1800s and the formation of industrial insurance. For much of that history, the focus was mostly on financial loss prevention and business interruption. But since about the mid-1980s, other impacts such as environmental damage, company reputation loss, loss of community trust, damage to neighboring properties and other aspects have become important to the engineering of new facilities. Many petroleum and chemical facilities have developed their own corporate standards that address such issues, or at the very least discuss those issues in a general sense for guidance to design professionals and facilities operators.

In the author’s experience, however, applying those considerations on a retroactive basis isn’t as clear a path as when designing a new facility. NFPA 30, and much of the guidance that uses NFPA 30 as a foundation, does not incorporate these perspectives, as such issues are outside the general scope of the NFPA system. API RP 2021 and most insurance standards also do not consider such issues within their scope, although more recent trends in both API and the insurance business suggest they are moving in that direction. API RP 2021 and insurance standards can, however, be implemented via the PSM process.

Given this, there appears to be a gap between the risk-management needs of owners and/or operators of tank farms and the design and management standards available. Further, risk-based analysis documents, such as Thomas Barry’s *Risk-Informed, Performance-Based Industrial Fire Protection* and the well-respected *Lees’ Loss Prevention in the Process Industries*, can offer significant information in the preventative, monitoring and mitigative portions of a risk framework, but lack detail on the responsive aspects while also relying on those responses to complete the overall risk picture [Barry, 2002; Mannan, 2012].

Conversely, there is little information in industrial fire fighter training, textbooks, periodical articles or similar industry information that suggest emergency responders could have greater influence in aspects that greatly affect them, such as engineering of new facilities, process analysis of existing facility, repair and maintenance schedules, loss prevention framework development and corporate insurance procurement.

Although a detailed discussion with ITC Deer Park was not undertaken, the two interviews with the ITC Vice President of Safety, Health, Environmental, Security, Regulatory Compliance and Operations suggest involvement of personnel involved with emergency response in such activities, though it is unclear as to what extent or influence. Additionally, older facilities such as the “First and Second 80’s” tank farm would only benefit from such input if it were evaluated on the whole, as opposed to individual operations or areas (see Section 5.3).

5.6 EQUIPMENT CONSIDERATIONS

When the “First and Second 80’s” tank farm was constructed, there was little in the way of fire-tested equipment and what equipment was on the market couldn’t be assumed to conform to a single standardized test. Historically, standardized fire tests for petrochemical equipment were established in the early-1990s as a result of a combination of large fires dating from the late-1970s into the mid-1980s and the risk-based drive to prevent or mitigate large fires through engineered controls (see Sections 5.3, 5.4 and 5.5). Although some fire testing approaches were available as far back as the mid-1960s, many of those were proprietary to petrochemical corporations and not shared with the remainder of industry.

Since the establishment of standardized fire testing in the early-1990s and industry-available equipment in the mid- to late-1990s, the use of fire-tested equipment has become relatively common. Equipment now available to industry include items such as:

- Safety shut-off valves – Control valves (such as butterfly valves and gate valves) that are heat activated to shut or open, depending on the desired position under fire conditions.

- High-temperature gaskets and pipe seals – Non-combustible or fire-resistant materials are used to ensure the flexible/semi-flexible joints at pipe connections do not burn or melt, and thus leak, during a fire situation.
- High-temperature electrical enclosures or devices – Fire-tested electrical equipment or protective enclosures that may perform monitoring or control of systems.
- Non-combustible and fire-resistive insulations – These insulations can augment thermal protection of other fire-tested equipment or be used to protect equipment, piping or tanks that is not fire-tested.
- Structural fire protection – Fireproofing materials such as concrete, spray-applied fire resistive materials (SFRM), intumescent coatings and water-spray systems can aid in protecting steel, concrete, hangers/supports and other items to ensure systems remain in place.

In addition to fire-rated equipment, other process-safety equipment now considered beneficial to fire protection came into more regular use during the period from the mid-1980s to the late-1990s. One important one is remotely-operated valves. These valves can be controlled through a variety of means, including electric-motor drives, pneumatic and hydraulic systems. While the technology dates to the 1930s, their implementation prior to the mid-1980s was relatively minimal due to the cost of the controls infrastructure. In the mid-1980s, when the early forms of addressable point technology became both cost beneficial and reliable, the ability to utilize remotely-operated valves increased significantly. The same was true of all remotely-operated equipment, including pump and motor controls, fire monitor nozzles and equipment shut-downs.

More traditional equipment, such as check valves, were also given greater consideration for their safety aspects. In the time before the PSM process became the norm in the industry, the quantity of any given piece of equipment in a system was minimized whenever possible, to reduce long-term costs and improve overall system reliability. In current approaches, however, the increase in safety that such items might offer, such as reducing the potential for a tank to drain uncontrolled, is balanced against the other cost and operational concerns.

As noted, few of this equipment was available or cost-effective at the time the “First and Second 80’s” tank farm was constructed, and obviously was not included in the original design. In general, incorporation of any of the above technologies would need to be considered as modifications and upgrades occurred over time.

A detailed review of all the equipment within the tank farm was not undertaken, but it is relatively clear from the fire events that the tank farm would have benefitted from many of them. Items such as safety shut-off valves, check valves, remotely-operated valves, and high-temperature gasketing could have had a sizable impact on the fire conditions. Moving away from the polyisocyanurate insulation would have also been beneficial. Although there are “fire retardant” formulations of polyisocyanurate, they are typically only advantageous for temperatures up to about 350°F (177°C).

The primary method of identifying and implementing these changes would have been through the PSM process (see Section 5.3) but could also have been achieved through reviews by insurance companies (see Section 5.4) or corporate risk evaluations (see Section 5.5). In general, documents like NFPA 30, FM LPDS 7-88 and API RP 2021 do not dictate the use of specific technologies, instead preferring to include performance or functional requirements that can be achieved with these technologies.

5.7 PERSPECTIVES ON INSPECTION, TESTING AND MAINTENANCE

In general, inspection, testing and maintenance is a well-known and well-regarded aspect of both fire safety and process safety, in general. In the author’s experience, two overbearing issues tend to rise to the surface in evaluating emergency preparedness or in assessing lessons-learned in post-accident situations.

One is that fire systems are often not given the same level of attention as other process safety systems. There are varying reasons that have been expressed by facility management across a large band of industry, but those can be grouped in perspectives of fire systems being expensive to repair or replace, choices in resource management, focus toward production in particularly demanding times and a lack of understanding of the impacts of relatively minor changes in system capabilities. There is little available information to support any conclusions with regard to ITC Deer Park in particular, but events from the fire and information obtained afterward suggest some items to discuss.

For example, interviews performed by CSB and the Harris County Fire Marshal's Office both note fire water system pressure being less than necessary to support use of monitor nozzles in the early stages of the fire [HCFMO, 2019; CSB Interview with ITC VP of Safety, 2019a; CSB Interview with ITC VP of Safety, 2019b]. According to ITC, the monitor nozzles initially activated by those first on-scene were not designed to reach the area of the Tank 80-8 piping manifold. The units adjacent to Tank 80-8 that were designed to reach the tank's piping manifold had become unusable due to the fire exposure, which damaged the monitor nozzles, and thermal exposure concerns to responders. Attempts to use the monitor nozzles further away from the fire area resulted in water streams not reaching the area, since the available pressure at the utilized nozzles was not high enough to support the reach.

Based on the provided information, an investigation of the water supply issues at the time of the fire uncovered a concern. Data from monitoring sensors on the water supply system, provided from ITC to the CSB, indicate rises and falls in water supply pressure during the early fire period appeared somewhat unusual [ITC Information, 2019a]. Fire pump test data from site fire pumps suggest that several were underperforming with regard to pressure at the flow rates that would have likely been impacting the monitor nozzle system early in the fire [ITC Information, 2019a]. The performance curves provided suggest available pressures were between approximately 88% and 95% of those presented by the manufacturer's original operating curve. There is also some indication that during the early stages of the fire, the pressure maintenance (jockey) pumps associated with the fire water system may have been operating, prior to starting of the fire pumps and giving a false impression of low pressure from the fire pumps.

While NFPA 25, *Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems* allows for a 5% reduction from the manufacturer's original curve, it is not unusual in industrial settings to find reductions more in line with those found at ITC Deer Park [NFPA 25, 2017]. Such reductions are often accepted on the premise that they do not greatly impact the effectiveness of installed systems. Whether that premise is supported by engineering analysis or other data is inconsistent across the industry.

When significant reliance is placed on manual firefighting equipment, the subsequent pressure reduction at hose nozzles can affect the distance water can be projected. A survey of multiple manufacturers and nozzle types suggested a 10% reduction in nominal operating pressure can affect reach distances range by 5 to 15 ft. When a target is at the far edge of the nozzle's projection distance, as Tank 80-8 would have been since it is in the center of the tank farm and the nozzles used are at the periphery of the farm, the water arc might not reach the target, or at least may not reach all portions of the target and reduce the capability to extinguish fire or provide exposure protection. Similar concerns exist for foam production in tank fire suppression systems, spray patterns or foam/water density in spray systems and other aspects of firefighting equipment.

The other issue is that facility operators and emergency responders don't always understand the important aspects of tank farm design that impact fire safety, but those aspects aren't related to fire protection systems. Ground sloping, containment wall integrity, drainage effectiveness and integrity of electrical equipment are all important aspects of fire protection at tank farms, but often do not get the attention they deserve. An in-depth evaluation of the ITC Deer Park facility could not be undertaken due to a lack of original design plans, and a post-fire evaluation would have provided inconclusive results in many cases. However, the descriptions provided in interviews and videos available in the public realm raise questions as to whether the sloping and drainage systems were operating as designed or intended.

6.0 Fire Modeling Efforts

In an effort to better understand the fire spread mechanisms during the ITC Deer Park fire, Jensen Hughes was requested to model a portion of the fire and examine the thermal outputs against thermal exposure criteria generally accepted within the industry. That effort is documented in a separate report found in Appendix A of this document.

The ITC Deer Park fire represented two unusual conditions compared to fires that are typically modeled: namely fire issuing from vents on the sides of the tanks near the roofline, as opposed to fire issuing from the pool surface or roof structure, and a combined pool fire at ground level and tank fire. A literature review performed to support the modeling effort indicated that most fire modeling performed for tank farms assumes either a fire at ground level or a fire within a tank at the fuel surface, but not both occurring at the same time. Reviewed reports indicate model efforts generally assume either a full surface fire or a partial surface fire, depending on assumptions regarding the roof structure of the tank, but did not assume a concurrent pool fire at ground level. Those that assumed a pool fire at ground level varied in their assumptions as to fire size and shape, but did not assume a concurrent tank level fire. Jensen Hughes searched but were not able to find any publicly available modeling efforts that evaluated fire issuing from the tank vents.

To perform the task, an approach needed to be developed to approximate the vent fires at the top of the tank. Since this type of fire is not incorporated as a standard fire or approach within most industry-available models, hand calculations were performed to estimate the evaporation rate of the liquid within the tank, which in turn established predicted vapor flow at the vents. The flow at the vents was incorporated into the computer-based model as a means of establishing flame size and length. Hand calculations for flame characteristics and exposures to adjoining tanks were also performed to establish comparability with computer-based model output.

The results of the detailed fire modeling and hand calculations indicate that the Tank 80-8 rim fire alone did not provide enough heat to cause the fire to spread to adjacent tanks. An additional heat source, such as a large liquid pool fire at ground level, allowed the fire in Tank 80-8 to spread to the adjacent tanks. The exposures to adjoining tanks from the tank roof-level vent fires were lower than might be expected for a fire involving a fuel surface, as is anticipated by prescriptive codes such as NFPA 30, *Flammable and Combustible Liquids Code*, FM Loss Prevention Data Sheet (LPDS) 7-88, *Ignitable Liquid Storage Tanks*, and API Recommended Practice (RP) 2021, *Management of Atmospheric Storage Tank Fires*.

However, the ITC Deer Park fire model demonstrated that the synergistic effects of the tank fire and pool fire at ground level were sufficient to lead ignition at adjoining tanks. The results of the study indicate that the coupled impact of a tank fire and a liquid pool fire may need to be considered in evaluating the minimum safe separation distance of future installations and to evaluate existing installations, particularly older installations that predate the availability of safety features or equipment that aid in mitigating such conditions. Although a relatively limited pool fire was examined in this analysis, the combined impact of the pool and vent fires significantly raised the radiant exposure to adjoining tanks. Were the pool fire expanded in the model, as it did during the ITC Deer Park fire, igniting the contents of adjacent tanks from radiant heat exposure would be more likely.

In addition, the computational modeling showed that the fires exiting vertical pressure release vents on the side of the tank behaved significantly differently than a standard liquid tank fire, where the impact of wind on the thermal exposure was significantly less than has been documented in similar studies for other tank farms. In this study, the size and number of pressure release vents had a more significant impact on the predicted thermal exposure than the wind speed. Because this configuration is a trend within the tank storage industry, additional study appears to be necessary based on clearly different burning and radiant exposure mechanisms that have traditionally been incorporated into the above noted standards. The configuration also highlights the need for prescriptive codes to consider alternative fire configurations when recommending minimum safe distances.

Readers are directed to the fire modeling report found in Appendix A for more detailed information.

7.0 Firefighting Considerations

There is not a detailed description available of the firefighting operations performed at the ITC Deer Park fire. While a plethora of data was generated during the operation through incident command processes, responses by external organizations, news footage, weather data collection, environmental-monitoring data monitors and post-incident interviews, much of that information is contradictory or incomplete and does not necessarily lend itself to building a detailed timeline of the response. This situation is typical of large fire incidents due to the chaotic nature of the events. Despite that, there is sufficient information to evaluate the operations in a general sense and extract lessons from the event.

7.1 GENERAL INDUSTRY TANK FIREFIGHTING APPROACH

In general, it should be recognized that there is no international or national requirement specifically for owners and/or operators of tank farms to provide firefighting capabilities. The decision of whether to provide an on-site response organization is based on a combination of local laws, loss control approaches, availability of capable off-site resources and general fire safety considerations. If it is decided that an on-site response organization is to be instituted, then a wide variety of national regulations, local laws, international standards, and other guidance becomes applicable.

Also noteworthy is that tank fire response tactics are largely defensive in nature. As discussed in Section 5.0, the codes and standards generally available for tank farm design are founded on an assumption of a single, large fire event that is allowed to burn out while various measures are applied to reduce the potential for spread to other tanks [Benedetti and Shapiro, 2018]. The form and function of those assumed responses, however, are not well described in any of those documents. Further, industrial fire response organizations have been historically acknowledged in fire protection and loss prevention documents of various types, but very little supporting documentation exists outside of the industrial firefighting sector [Kelly et al, 2003].

As demonstration of this, dedicated industrial fire organizations have existed at petroleum and chemical industry facilities, including tank farms, since at least the 1930s [Kelly et al, 2003]. Their strategies and tactics have adapted over time, and they've been incorporated as crux elements of process safety and corporate risk management strategies since at least the mid-1960s. Schools specializing in industrial firefighting, such as the training program at Texas A&M University, have existed since at least the early-1960s, with some having their early stages founded in the mid-1950s. Information sharing among the industry was, and continues to be, the primary form of transferring those approaches, as opposed to dedicated schools, training academies or indoctrination programs that exist for structural firefighting and other response activities performed by pubic fire departments.

The period from the early days of industrial firefighting to the mid-1970s tended to allow for both defensive tactics, due to acceptance of the consequences by the public in general, and sometimes aggressive tactics, due to a general acceptance of injury and life loss among firefighters, responders and plant personnel [Kelly et al, 2003]. During that period, dedicated fire services did exist, but plants were often assisted greatly by non- response personnel that were either expected to respond by their site management or volunteered for the effort [American Insurance Association, 1968]. Since the mid-1970s, however, industrial emergency responders have been subject to greater control, which has eliminated the "all-in" strategy that underlies much of the pre-1980 loss data for tank farms [NFPA 600, 1986].

Concerns for industrial firefighters, and plant personnel in general, were part of the formation of the Occupational Safety and Health Administration in the early-1970s and closer inspection of fire concerns in the United States was the focus of the efforts of the National Commission on Fire Prevention and Control, which produced the *America Burning* report of 1972 [NCFPC, 1972]. Those two movements led to national regulations and a general movement toward improved protection for firefighters. A variety of fire protection organizations worked with federal organizations to address public-sector fire response organizations, but OSHA was able to regulate protections for industrial fire response organizations through existing structures, resulting in required protections via 29 CFR 1910.156 in 1980 [45 FR 60706, 1980]. Similar issues with emergency response to hazardous materials in the latter-1980s eventually resulted in the protections included in 29 CFR 1910.120 [61 FR 9227, 1996]. That worker-protection movement and eventual regulation emphasized the shift toward defensive and more cautious attack strategies and tactics within the industrial firefighting realm. As well, the regulations in 29 CFR 1910 preclude personnel that are not specifically trained and incorporated into the emergency response organization from responding in ways that would endanger them, effectively ending the "all-in" strategy of the past. In some cases, the risk of injury or death of plant personnel, as well as concerns over prosecution under federal regulation, has led many sites to reduce or eliminate their in-house response organizations.

Further influence on response organizations and their operations within tank farms comes from API and NFPA. The movement primarily driven by 29 CFR 1910.156 helped to quickly mature NFPA 600, *Standard on Facility Fire Brigades* from its predecessor (then titled as NFPA 27) [NFPA 600, 1981]. While it would take nearly a decade, more specific training and knowledge requirements for responders came in the form of NFPA 1081, *Standard for Facility Fire Brigade Member* in 2001 [NFPA 1081, 2001]. API RP 2001, through revisions starting in the 1991 edition and moving forward, included more details from industry experience and began incorporating incident command roles and plant functions (such as control room operators, process functions, etc) in their information on response [API Pub 2021, 1991; API RP 2021, 2015].

This history is important because the "First and Second 80's" tank farm design, as well as much of the basic assumptions of NFPA 30 and its derivatives, straddles those two eras. As previously discussed, the underlying presumption of an emergency response within a somewhat short but ill-defined response timeline tended to be more easily met in the mid-1970s and prior, given the "all-in" response approach that was present during that era. Since the mid-1970s, the "organization only" response approach has led to needs for more structured incident command, initial response protocols, call-in and call-back procedures, readiness procedures for equipment and apparatus and more. While these infrastructures definitely augment the response capabilities over the long duration of the response, there is often a longer initial response delay. Because of that, there are open questions as to whether the design standards for tank farms, as well as other industrial processes, have kept pace with the newer emergency response infrastructure and properly incorporate it into design or process safety efforts.

It should also be recognized that it has long been accepted that individual sites generally do not have sufficient capabilities to perform tank firefighting activities on their own [Factory Mutual, 1967; API RP 2021, 2015]. The three-tiered response structure described in Section 4.0 has been in place since approximately 1960. Prior to that date, large mutual aid pacts existed and were well utilized in large incidents. The founding of the Red Adair Company, Inc. in 1959 added the top tier of highly-specialized responders to the mix, with those organizations becoming a regular part of the response framework by the early-1970s. By the time the "First and Second 80's" tank farm was constructed, the framework was standardized within the industry, though as described in Section 5.0 incorporating that response capability into facility design and continued operations is a continuing issue.

7.2 GENERAL FIREFIGHTING INFORMATION

Note that the information contained herein is condensed from the overall fire timeline presented elsewhere, and is intended to provide some supporting information for the remainder of Section 6.0 of this report. The information contained in this section is not meant to be a complete timeline of emergency response into the fire area.

Information derived from interviews contained in other documents indicates that the initial response into the area was staffing of monitor nozzles (two or three are identified, depending on source), with ITC Deer Park emergency response team apparatus arriving on scene as the team was organized and a plan of attack formed [HCFMO, 2019]. The apparatus responded into the containment area at the northeast corner, positioning between Tanks 80-10 and 80-13 to achieve the best angle of attack on the ground fire at Tank 80-8 and the exposure to Tank 80-11 [CSB Interview with ITC VP of Safety, 2019b]. Interviews also suggest the location was chosen due to winds blowing from approximately the north/northeast.

By approximately noon on March 17, 2019, the ITC Deer Park emergency response team had activated their association with adjoining facilities and public emergency response agencies via the Channel Industries Mutual Aid (CIMA) group [CSB Factual Update, 2019]. As additional apparatus and personnel began to arrive during the afternoon of March 17, these additional resources were positioned within the containment area, predominantly on the east and north sides due to wind conditions and apparatus access availability [CSB Interview with ITC VP of Safety, 2019b]. By this time, fire had spread to Tank 80-11.

The installed monitors east of Tank 80-8 were damaged due to proximity of the fire and useful monitors at the south perimeter of the tank farm were exposed to smoke and direct flame, making them unsafe to use [CSB Interview with ITC VP of Safety, 2019b]. Monitors on the north side were noted to be ineffective by responders, due to low water supply pressure, and the use of those monitors was mostly abandoned by the time apparatus was in place. Remaining installed monitors around the perimeter would have been mostly incapable of supporting operations in the initial fire area for similar reasons.

During these initial hours, movement of personnel or apparatus to the southern part of the containment area quickly became a safety concern, either from large quantities of smoke due to wind direction or direct flame exposures as burning material moved in that direction [HCFMO, 2019; CSB Interview with ITC VP of Safety, 2019b]. Therefore, there was an inability to utilize the tank foam suppression systems, which are all manually supplied (no connected water supply) [CSB Interview with ITC VP of Safety, 2019b]. The inability to access the foam supply location augmented other considerations about tank fill height on Tank 80-8 specifically (see Section 7.3) in not operating the tank foam system early in the response.

Information provided by ITC Deer Park to CSB indicates that within the first hours of the response, the deployment included [Baker Botts, 2020b]:

- Personnel operating three fixed monitors (500 gpm rated nozzles)
- ITC Deer Park Fire Engine 3, employing 2,500 gpm rated engine-mounted monitor and deployed 1,250 gpm rated ground monitor
- ITC Deer Park Fire Engine 2, employing two monitors rated for 2,000 gpm each
- Personnel activating the deluge system for the west tank farm manifold (water spray system)
- Three CIMA quick attack vehicles, each with 2,000 gpm rated monitors
- One CIMA trailer-mounted monitor rated for 2,000 gpm
- Four CIMA 500 gpm rated ground monitors
- Two Port of Houston fire boats, rated for 5,000 gpm each (water supply only – no firefighting), pumping from the Houston Ship Channel
- Operation of all four ITC primary fire water pump (combined rated capacity of 13,500 gpm, estimated actual around 11,000 gpm based on testing records provided to CSB for some pumps), pumping from the Houston Ship Channel

Additional apparatus, equipment and personnel arrived during the first 24 hours of the event, but the exact timing and deployments are not clear from the available information.

Over the period from the afternoon of March 17 through the evening of March 18, the available information suggests that fairly typical response tactics were employed, albeit with greater numbers and quantities than if the event were a ground fire or tank fire alone. From limited video evidence, it is clear that foam application to burning surface fires (both in the tanks and on the ground) was being performed, as was exposure protection for tanks and piping systems and for responders on the ground. The latter is an often-employed technique to ensure safety of the personnel and response equipment.

The decision to contract US Fire Pump on the evening of March 18 would introduce additional personnel, equipment, and tactics to the operation by early morning on March 19 [CSB Factual Update, 2019]. The US Fire Pump team, according to interview information, brought additional personnel, which allowed relief of existing responders, and large-capacity, high-velocity monitor nozzles (specific makes and models could not be clearly determined from available information), which allowed for more effective deployment of foam. The US Fire Pump team, based on magazine articles that were published subsequent to the fire event, appears to have employed more aggressive tactics, as well, though the base information available for the fire event is not clear on those assertions [Riecher, 2019a; Riecher, 2019b].

7.3 GENERAL RESPONSE PERSPECTIVES

Overall, an examination of the data suggests a traditional emergency response to a tank farm, employing tactics that have become relatively well described in industry magazines, limited texts on industrial firefighting and the tactics taught at training schools. As noted above, providing a mix of exposure protection and direct fire suppression is the most commonly applied approach, and that approach was evident from the available information.

The ability to deploy foam fire suppression to the tanks was hindered over the duration of the fire due to safety concerns associated with response to the south side of the containment area. Although early deployment to the area and foam system activation might have been achievable, as was done for the water spray system on the west manifold, it is not clear that significant benefit would have been derived. Use of foam fire suppression systems on tanks assumes that a single tank is on fire and the goal is to suppress the fire until emergency forces can respond and to limit exposures to other tanks. While such systems often full extinguish fires, the base design assumption is reduction of hazard.

The decision to not deploy the foam suppression system on Tank 80-8 during the early fire stage would typically been seen as a point of debate. Interviews with the ITC VP of Safety revealed that the decision was made due to a combination of concerns, primarily based on fire and smoke conditions at the southern perimeter. As well, there was a concern that the tank had been filled to near capacity and the potential for subsequently overfilling the tank by applying foam [CSB Interview with ITC VP of Safety, 2019a; CSB Interview with ITC VP of Safety, 2019b]. The issue of wind direction and fire exposure is a common one and would likely have been a point of concern for any responder. The concern expressed by the ITC VP of Safety about tank capacity and overfilling might be challenged by some, however is certainly a valid safety concern. Spillage from the tank would have, at that point, exacerbated the fire and introduced an unknown fire spread element. Obviously, that decision had implications toward the actual timeline. Alternative assumptions about the performance of the system and impact on the timeline would be pure speculation, however. While one can easily assume some effectiveness based on past performance of such systems in general, the concerns about the fill height of the tank could just as easily translate to ineffective deployment of foam from the generator chambers inside the tank (due to partial or full submersion) or loss of foam through the overfill vent. In either case, ineffective suppression would still lead to extensive fire spread conditions, although such conditions may have been delayed.

Another point of discussion that might arise is whether or not more resources, or a different mix of resources, could have been added to the operation. A review of the initial response as noted above, additional resources included in incident command reports and noted apparatus or monitor locations identified in interviews suggests that the inability to introduce more resources was a combination of safety considerations, ability to access the fire between tanks, the inability to loft water from long distances outside the tank farm and fire conditions making advantageous locations inaccessible.

The tank farm is only accessible at points on the north and south, with the latter having been quickly compromised and eliminated as access for the majority of the response. The same is true for access to installed fire protection connections at the south. Initial apparatus setups quickly took up the most advantageous locations, which allowed hose streams to flow between tanks and onto exposed tank surfaces. But as more apparatus arrived and more monitors were placed, the area taken up by apparatus, hoses, trailers, ground monitors and other equipment, as well as the needed safe working space around each, precluded adding too many other resources. While space might have been available, the effectiveness of those resources would have been limited by the tank configuration and ability to access the fire. At some point, adding more apparatus would have also impacted the ability to retreat out of the tank farm should the incident challenge those positions. That action became necessary as the tank exposures led to fires in the tanks and the ground fire spread northward, forcing resources established within the containment area to pull back or to be abandoned [CSB Interview with ITC VP of Safety, 2019b; IFW, 2020].

The ability to place apparatus outside the containment area is also problematic. On the north side of the tank farm, between the north containment wall and Tidal Road, is a ditch that disallows apparatus from being set any closer than the south side of Tidal Road. That would necessitate foam streams to reach nearly 300 ft before being effective on the fire. While monitors on fire apparatus can reach those distances, foam or water will tend to disperse and become ineffective on a large fire such as this one, even when wind conditions are not considered. Therefore, use of apparatus at that location would actually have been harmful to the response, by utilizing available water flow and pressure to little advantage at the fire.

Similar conditions existed at the other perimeter locations for various reasons. On the east side, the plant road just to the east of the tank farm was the extraction point for those resources inside the containment area, and therefore could not be used until later in the fire, once resources within the containment area could no longer remain there. The next available spot would have been on Independence Parkway, putting the apparatus at distances 375 ft or more from the fire, and having existing resources in between them and the fire, for large portions of the response. Resources could locate there once the fire spread to tanks closer to the east side of the farm. On the west side, pipe racks and electrical equipment would have pushed resources to the west to allow for beneficial foam stream arcs. If foam or water streams are arced too high, they begin to break apart due to gravitational and velocity forces, thus making them ineffective. To achieve lower-angle arcs, apparatus would have had to set up closer to the railroad siding at the west side, putting the distance to fire at about 350 ft. The same condition exists at the south and would be problematic even if the location wasn't compromised by fire at that point. Further, movement south to achieve good foam stream angles would have put apparatus between tanks to the south (in the "Third 80's" tank farm), obstructing their view of the situation and placing them in further danger.

In most tank fire situations, the ability to obtain sufficient resources is a commonly cited issue. In this case, however, the main issues appear to have been available space for operations and the ability to deploy water/foam streams in an effective manner given the tank farm layout. A review of the number of apparatus, pumping capabilities, foam supplies and other aspects suggests that more than adequate resources were available at the outset of the operation. The limitations of available space and access appear to have impacted the ability of getting those resources into the tank farm and into advantageous positions.

As demonstration of that, the effectiveness of the US Fire Pump plan and execution appears to stem more from the use of newer, larger-capacity equipment and more directed efforts, as opposed to simply more personnel and apparatus [Riecher, 2019a; Riecher, 2019b]. The larger-capacity equipment gave the response team the ability to loft foam in extremely large quantities toward the core areas of individual fires, which the ITC and CIMA equipment could no longer reach. By attacking individual fire areas, including the ground fire, the team was able to extinguish tanks one-by-one and reduce the size of the ground fire. Also contributing to the extinguishment was a supply of an improved foam, brought by the US Fire Pump team, which was not yet commercially available.

7.4 RESOURCE AVAILABILITY

As noted in the previous section, there do not appear to be obvious concerns with resource availability for much of the response. From the information made available, sufficient apparatus, personnel, monitors, hose, foam, and other resources appear to be available for a fire of a more typical progression. The unique situation with this particular fire doesn't appear to have challenged the amount of resources as much as the ability to deploy them.

One issue that does stand out, however, relates to obtaining assistance from US Fire Pumps. Jensen Hughes was not privy to the contract timing and arrangement between ITC Deer Park and US Fire Pumps, but the information provided by CSB and that in the public realm indicates that no contract was in place at the time of the incident. As well, no contract or relationship beyond the local mutual aid agreements noted previously was in place, based on the available information. The resulting administrative delays and gathering of resources by US Fire Pumps hindered quickly bringing those resources to bear. Although third-party contractors like US Fire Pumps have been in existence for some time, advocacy for standing contracts or rapid implementation of contracts became standard practice in the mid- to late-1990s. The 2001 release of API 2021 (Fourth Edition) was the first to mention such arrangements [API RP 2021, 2001], with industry recognition of the need for those relationships based on fires that occurred during the two previous decades.

7.5 PRE-INCIDENT PLANNING

Limited pre-incident planning information was released by ITC Deer Park for review by the CSB. The information provided suggests typical information sheets for the tank farm, identification of initial apparatus and equipment for deployment, location of those resources, suggested number and placement of personnel and similar data. That information is augmented by knowledgeable personnel, which is evidenced from information in interviews and the immediate response tactics.

From the limited information available, there do not appear to be any lessons learned that would be specifically extracted from this event. There have been long-standing recommendations in the industry to transfer information from personnel onto response plans and to augment plans with more detailed information on engineered systems and their potential contributions or drawbacks to response. That recommendation would likely have had some benefit to this response, but how much of a contribution cannot be easily determined. As that lesson is not unique to this situation, it was not examined further. However, a need for reinforcement of that existing lesson is noted.

7.6 PRE-INCIDENT TRAINING AND DRILLS

Although requests were made to ITC Deer Park and CIMA for training information and records, that information was rebuffed. Therefore, there is little ability to judge whether or not the training developed by these organizations for tank farms reveals any lessons to be learned. Both acknowledged through responses to requests for information that they have robust training programs that align with industry standards. Given information contained in interviews and the relatively rapid deployment of resources during the initial phase of the response that training on the level asserted is likely. It is not clear from the event, however, that the training incorporated the various weather-related, slope/drainage and apparatus placement issues described herein. While “improved training” is an often-cited lesson learned from large industrial fires, this particular one emphasizes some of those in specific areas for training and drills, involving scenarios considered unlikely, incorporating worst-case conditions (for example, wind directions, access failures, etc), involving process or engineering personnel in the training/drill scenario development and delving deeper into “what if” questions during planning and drills (such as, What if we can’t access this area?, What if we lose this pump?, What if we need X-many apparatus in this area?).

8.0 Potential Lessons Learned

From the evaluation provided herein, it is clear that the ITC Deer Park fire represented a significant challenge to responding firefighting organizations. However, the examination of various aspects surrounding the tank farm, its operating conditions, the firefighting operations and potential exposure conditions suggests that specific underlying conditions contributed to the event in significant ways. From those considerations, potential lessons learned are suggested to the CSB for consideration for incorporation with lessons learned that may have been derived outside of the Jensen Hughes effort. The lessons learned provided herein are provided in no particular order, as their importance or effect will differ for each reader of the final CSB package of information.

1. Improved education on the baseline assumptions of tank farm fire protection design is needed. The investigation of the ITC Deer Park fire highlights that guidance documents available for tank farm design (such as NFPA 30, API 2021, FM LPDS 7-88, and others) assume specific scenarios that require emergency response. The ITC Deer Park fire demonstrated that operations within tank farms can lead to

fire scenarios not assumed by the implemented tank farm design standard. In this specific case, the NFPA 30 approach does not address the potential for the combination of a ground and tank fire. Over the long term, understanding the basis of the design standard can help better guide future management of change and emergency response.

2. Similarly, understanding of the design basis fire scenarios must be better understood for corporate risk management. The ITC Deer Park case demonstrates a disparity between risk profiles assumed by the original design, emergency responders, corporate risk managers and insurance companies. Better understanding of the underlying assumptions of the design standard would better inform the other parts of the risk and response structures.

3. Improved information sharing between engineering teams and emergency response agencies is needed. The initial design of the ITC Deer Park “First and Second 80’s” tank farm generally complied with NFPA 30 requirements at the time of construction, but deviated from that standard with respect to drainage, tank layout and number of tanks within the same containment area. Although not deviations, choices regarding fire system design (in this case, manual supply versus automatic supply) and placement of fire system connections also had an impact on response. It is not clear that emergency responders understood the impact of those decisions prior to the fire event.

4. Improved information sharing and involvement between technical teams and emergency responders is needed prior to making modifications to tank farms that could potentially impact response capabilities in the event of a fire. The configuration of the tank farms, and the operations therein and at the perimeter, had obviously changed from original construction to the time of the event. The impacts of expanding pipe racks, adding piping and pumps and changing access necessarily adapted response planning over time. The ITC Deer Park fire exhibited some of those impacts not just in the initiating event, but also in the ability to respond to the west and south sides of the facility.

5. Better recognition of the contribution and importance of systems other than fire suppression and detection systems to emergency response appears to be needed. The ITC Deer Park fire reinforced that systems such as mechanical piping, drainage systems and electrical systems are important to preventing and mitigating fire conditions, and that they can influence the growth and spread of fire and the ability to respond when they do not perform as intended.

6. Process safety management (PSM) requirements have changed, and tank farms should be examined in closer detail. As well, a wider cadre of personnel should be in included in that effort. Operations like the blending performed at Tank 80-8 has been clarified by OSHA to fall under PSM guidelines. However, consideration of implementing PSM even when such analysis may not be applicable (such as well simple filling/emptying is performed) would be beneficial. As well, including emergency responders, maintenance staff and field operators in such efforts would greatly enhance the efforts of more technically-oriented personnel.

7. Consideration of upgrading facilities with newer safety equipment is needed. A significant shift in the type and availability of safety equipment occurred from the late-1980s through today. Tank farms constructed prior to the mid-1990s, when such equipment became readily available, should be revisited to determine if such equipment could aid in avoiding coupled accident, such as this one at the ITC Deer Park tank farm. This effort is encouraged even if the PSM process is not implemented for a given tank farm.

8. Contracting for third-party fire response services should more closely examined by tank farm owners. Recent fire histories and guidance via API RP 2021 and other documents highlights the need for third-party response agencies, but the ITC Deer Park fire also emphasized the need to either have a standing relationship in place or the ability to quickly contract for such capabilities. Overall, such services should be viewed in the same light as oil spill removal organizations (OSROs), environmental contaminant responders and more traditional fire responders (that is, local emergency response teams and mutual aid associations).

9. Some of the long-standing issues and recommendations within the industrial fire response industry were re-emphasized by ITC Deer Park fire. While such issues were not examined in detail for this fire, the event stands as a reminder to facilities to address pre-incident planning, training, drills, and similar preparatory efforts. What the ITC Deer Park response may demonstrate is a greater need for more detailed training or drill efforts and a need to include events that are considered unlikely.

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- Engineering Drawings
- Fire Water System Drawings
- Fire Foam Use Data
- Fire Pump Operations Data
- Fire Pump Testing Reports
- Fire Water Data
- Incident Command Forms
- Insurance Survey/Loss Prevention Reports
- Management of Change Authorization Forms
- Piping and Instrument Diagrams
- Response Partners List
- Secondary Containment/Drainage System Information

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- Update/Statement 2, March 17, 2019, 3:30 pm
- Update/Statement 3, March 17, 2019, 7:00 pm
- Update/Statement 4, March 18, 2019, 1:30 am
- Update/Statement 5, March 18, 2019, 5:30 am
- Update/Statement 6, March 18, 2019, 10:00 am
- Update/Statement 7, March 18, 2019, 3:00 pm
- Update/Statement 8, March 18, 2019, 10:00 pm
- Update/Statement 9, March 19, 2019, 2:30 am
- Update/Statement 10, March 19, 2019, 10:00 am
- Update/Statement 12, March 19, 2019, 9:45 pm

- Update/Statement 13, March 20, 2019, 4:00 am
- Update/Statement 21, March 24, 2019, 10:00 am
- Update/Statement 24, March 26, 2019, no time indicated

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Appendix A – Modeling Report

A-1.0 Introduction

At the request of the US Chemical Safety and Hazard Investigation Board (CSB), Jensen Hughes was requested to analyze the fire events which occurred from Sunday, March 17, 2019 through Saturday, March 23, 2019 at the Intercontinental Terminals Company, LLC (ITC) tank farm in Deer Park, Texas.

This report presents results from fire and heat transfer modeling of the tank-to-tank fire spread observed in the ITC fire. This report builds upon the observations documented in the previous Jensen Hughes report, "Perspectives on Tank Farm Fire – ITC Deer Park (Texas) Facility, March 2019" [1]. The report includes general information on the ITC fire, a review of the technical literature relating to tank farm fires, and a discussion of the fire modeling analysis performed in this work.

A-2.0 General Information

This section provides an overview of background information related to the tank farm, the progression of the fire during the incident, and computational fire modeling.

A-2.1. DEER PARK, TEXAS TANK FARM LAYOUT

Figure A-1 provides an aerial view of the ITC Deer Park terminal prior to the fire (obtained via Google Earth Pro software) [2]. Figure A-2 provides the contents of the tanks in the "First and Second 80's" tank farm where the fire occurred. All tanks were filled with combustible liquids other than tanks 80-9 and 80-12, which were empty at the time of the incident. All tanks except 80-9, 80-11, and 80-12 were equipped with a floating roof to reduce the evaporation rate of fuel [3]. Each tank measured 110 feet in diameter and 48 feet in height, and was separated from adjacent tanks by approximately 36 feet [4]. The floating roof consisted of a 108 foot, 8.4 inch diameter pan (steel or aluminum) [4]. A schematic of the tank geometry and separation is shown in Figure A-3.

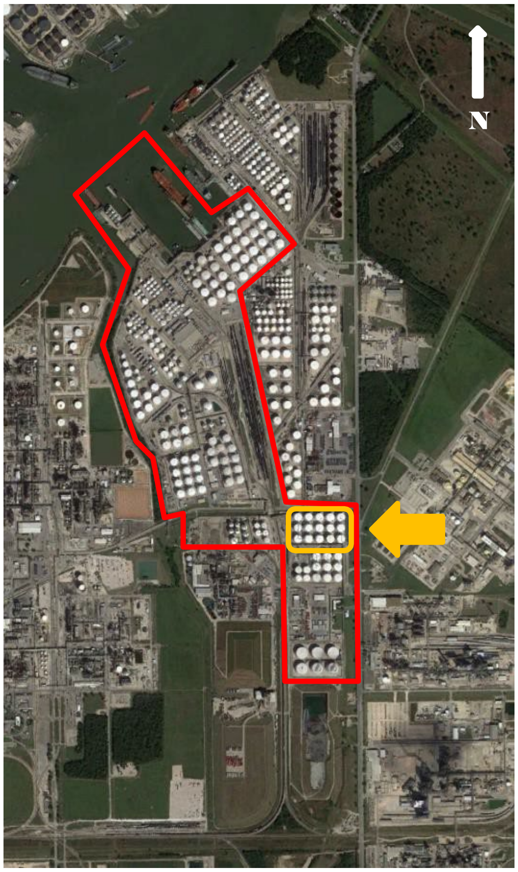


Figure A-1. ITC Deer Park, Texas Facility with "First and Second 80's" Tank Farm Highlighted (Imagery Date: October 28, 2017) [2].

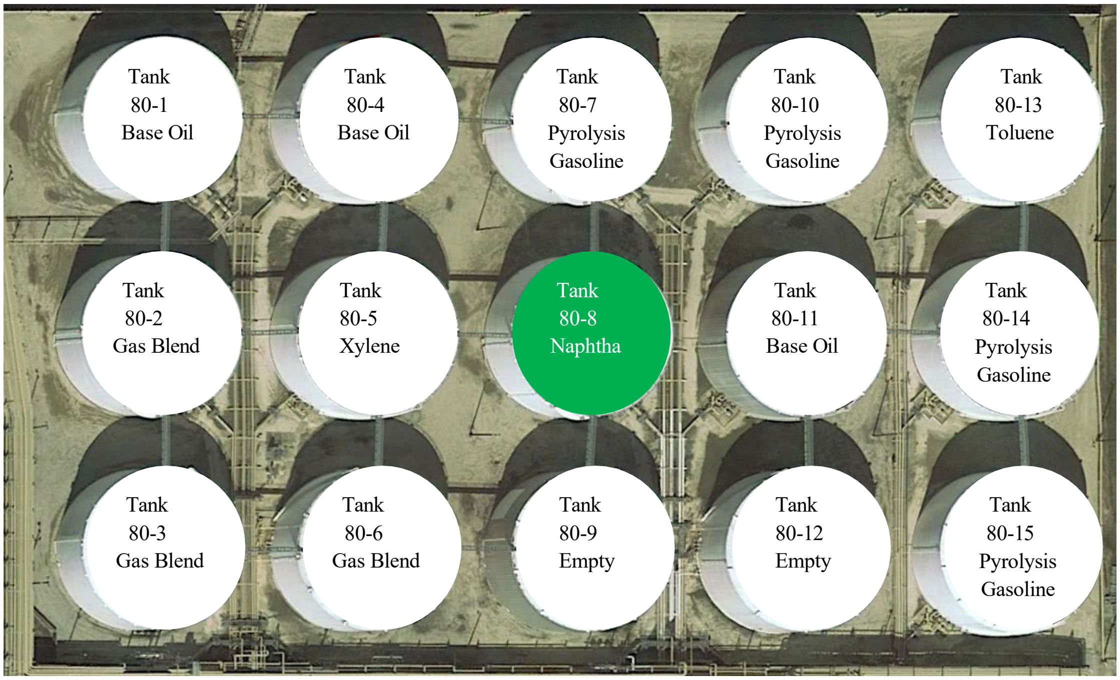


Figure A-2. "First and Second 80's Tank Farm" Tank Numbers and Contents at Time of Fire (Imagery Date: October 28, 2017) [2] (Contents from ITC Press Releases) [5] (Tank 80-8 highlighted in green).

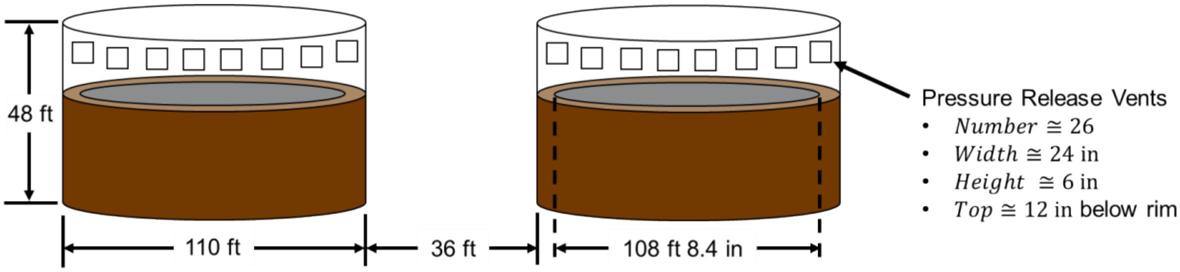


Figure A-3. Schematic of Tank 80-8 geometry and separation.

A-2.2. INCIDENT RESPONSE AND FIRE PROGRESSION

The incident response and fire progression for the ITC Deer Park established by the CSB team under separate cover was used to determine potential fire growth mechanisms. Of note is the length of time that Tank 80-5 took to ignite (approximately 7 hours after fire initiation) and the time indicated for subsequent ignitions (Tanks 80-2, 80-3, 80-6, 80-9 and 80-11 within 6.5 hours after ignition of Tank 80-5). Based on industry experience, this progression suggests radiant energy ignition of the tanks as opposed to direct exposure ignition.

A-2.3. ENVIRONMENT CONDITIONS

Figure A-4 and Figure A-5 show the wind conditions near the tank farm, taken from the weather station at Houston Ellington AFB (KEFD). The location of the weather station with respect to the tank farm is shown in Figure A-6. The weather station was located approximately 10 miles south-south-west of the tank farm.

Note the direction shown in Figure A-4 corresponds to the direction from which the wind was coming with respect to the tank farm. Figure A-4 shows the wind was initially coming from north-north-east during the day of 3/17/2019 but transitioned to south-south-east during the evening of 3/17/2019. During the morning of 3/18/2019 the wind transitioned to east-north-east for another day until it moved to a southerly direction in the evening of 03/19/2019. Figure A-5 shows the wind speed during the day generally ranged from 10-15 mph, with lower speeds of 0-5 mph in the evenings.

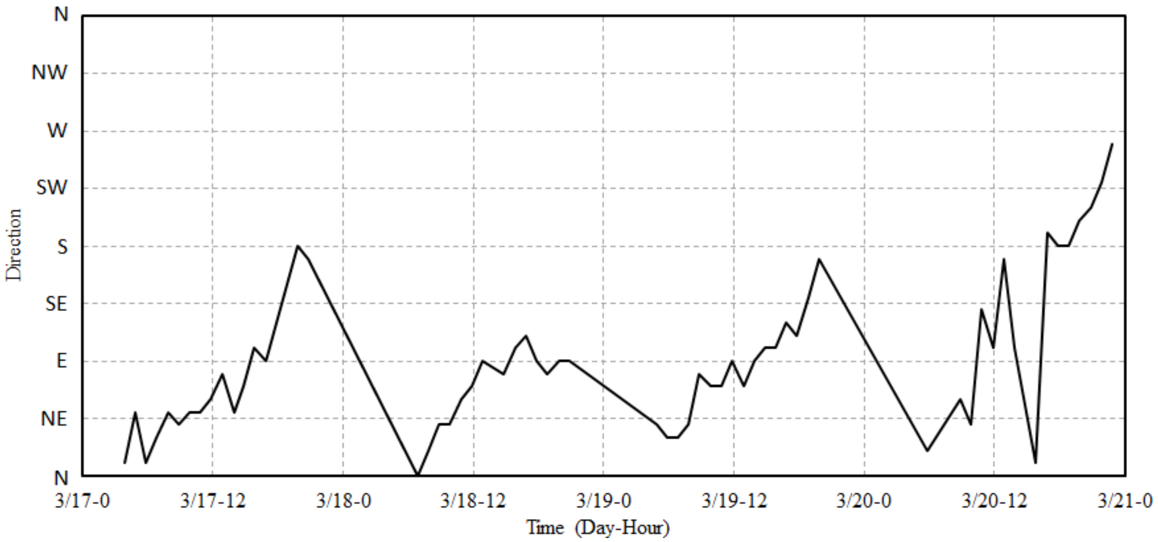


Figure A-4. Wind direction [Source: National Oceanic and Atmospheric Administration [6]].

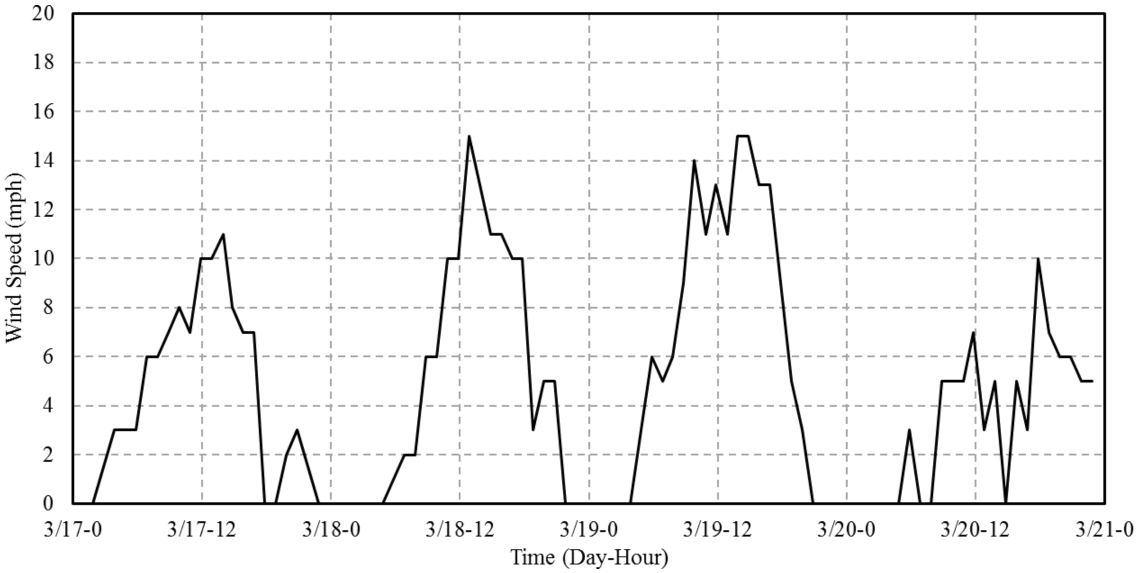


Figure A-5. Wind speed [Source: National Oceanic and Atmospheric Administration [6]].

A-3.0 Literature Review

Although the primary goal in tank farm fire protection is to avoid fires entirely, the secondary objective is to keep fires small to prevent large-scale fire spread and structural failure. One methodology which can be used to prevent large-scale fire spread is to increase separation distance between tanks to reduce the likelihood that a burning tank will ignite adjacent tanks. The minimum safe separation distance is defined as the distance where the heat transfer from one burning tank to an adjacent tank is insufficient to ignite the adjacent tank. The following subsections provide an overview of existing safe separation distance recommendations and analysis methodologies.

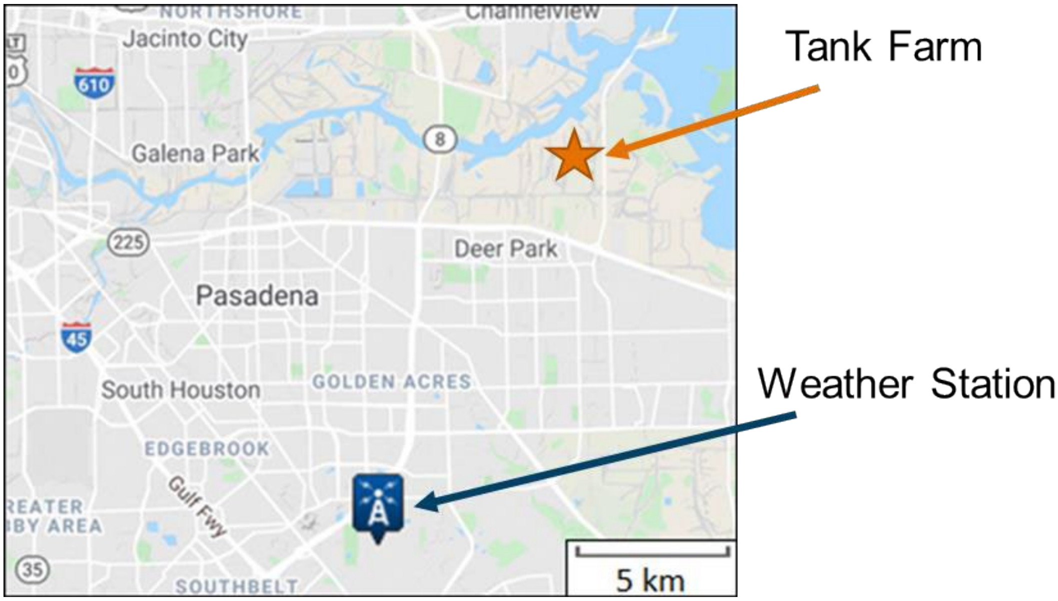


Figure A-6. Weather station location relative to tank farm [Source: Google maps [7]].

A-3.1. PRESCRIPTIVE CODES

Minimum safe separation distances are provided in several prescriptive codes such as *NFPA 30: Flammable and Combustible Liquids Code* [8], *FM Loss Prevention Data Sheet (LPDS) 7-88: Ignitable Liquid Storage Tanks* [9], and *API Pub 2021: Management of Atmospheric Storage Tank Fires* [10]. While the specific recommendations in NFPA 30, FM LPDS 7-88, and API Pub 2021 diverge somewhat, the general framework is the same. The following outlines a few key assumptions in these approaches.

- The safe distances are designed to address tank-to-tank fire spread events.
- The fire scenarios are based on probabilistically likely situations, as opposed to worst-case conditions.
- The size of fires are based on tank diameter, and industry-accepted failure probabilities (such as limited size openings in pipe systems) [11].
- Radiant exposures based on a single fire location (such as a tank liquid surface, or spill fire).
- Radiant exposures are estimated based on small scale experiments and data from historic tank-to-tank fire spread events.
- Radiant exposure thresholds vary significantly ranging, from 4.7 kW/m^2 (burns human skin after 30 s) [12], 7.0 kW/m2 (maximum tolerable value for firefighters in personal protective equipment) [12], to 8.0 kW/m^2 (limit to ignite an adjacent tank) [13].

While these codes provide conservative estimates for many scenarios, the specific scenarios observed in the fires at ITC did not align with several of these assumptions. These differences are outlined in Section 3.3.

A-3.2. PERFORMANCE-BASED ASSESSMENTS

The minimum safe separation distance is a function of the heat transfer from the flame (or radiant heat flux) as a function of distance and the critical radiant flux required to ignite an adjacent tank. Predicting the heat transfer in a tank farm fire is complex, requiring detailed information on the tank farm geometry, atmospheric boundary layer, liquid fuel evaporation, and combustion reactions. Researchers have developed several fire modeling approaches to predict the radiant heat transfer to adjacent tanks, each with varying levels of complexity of the physics.

Beyler provides an overview of hand calculation-based approaches used to predict heat transfer for large, open hydrocarbon fires in the SFPE handbook [14]. The Shokri and Beyler correlation provides an order of magnitude estimate of the radiative heat flux,

$$q'' = 15.4\left(\frac{L_c}{D}\right)^{-1.59} \qquad (1)$$

where q'' is the heat flux, L_c is the length from the center of the pool, and D is the pool diameter [15]. Comparisons with experimental data show this approach reasonably reproduces the mean heat transfer observed in the experiments. However, the heat fluxes observed in the experiments have significant scatter which is not reproduced with this model (on the order of 10x lower, and 2x higher).

The point source model presented by Drysdale assumes the heat transfer from the flame is emitted by a single point at the center of the flame [16]. The heat flux is predicted using the equation,

$$q''_c = \frac{Q_r \cos\theta}{4\pi R^2} \qquad (2)$$

where Q_r is the radiant energy released by the flame, θ is the angle between the normal to the target and the line of sight from the target to the center of the flame, and R_c is the distance from the center of the flame to the target. Similar to the Shokri and Beyler correlation, the point source method reasonably reproduces the mean heat transfer, but does not reproduce the scatter observed experimentally. Drysdale notes that the point source method is primarily applicable far from the fire, and a factor of 2 should be applied to any heat fluxes predicted to be less than 5 kW/m^2.

The two hand calculation approaches previously discussed were developed for diffusion flames under no wind conditions; however, Mudan has shown that wind tilting the flame towards an adjacent tank leads to higher exposures which are not captured in these approaches [17]. More detailed modeling approaches are needed to account for the impact of wind on the thermal exposure.

The simplest approach to account for the impact of wind is to modify the point source model based on empirically derived flame tilting data, such as in the approach presented by Sengupta [18]. In this approach, the extension of the flame is calculated using the dimensionless wind speed, and the flame tilt is calculated based on the ratio of the dimensionless wind speed and the maximum velocity within the fire plume. The new center of the flame is then used as the center in the point source model. While this approach provides reasonable estimates of the heat flux under different wind conditions, it inherits the same limitations as the standard point source model.

Mudan presented an alternative approach to predict the heat flux from a tilted pool fire based on view factor calculations from an inclined cylindrical source (representing a tilted flame) [17]. The flame extension and tilt are calculated using a similar approach to that presented by Sengupta. The inclined cylinder provides a more realistic representation of the flame shape than the point source model; however, this method has been shown to provide non-conservative estimates compared to experimental results [14].

The previously described approaches are all hand calculation-based methods. An alternative approach which has seen increased use in recent years is to use computational fluid dynamics (CFD) to predict the heat transfer from a flame to an adjacent tank. In a CFD fire model, the computational domain (including the fire, smoke, and surrounding environment) is discretized into small control volumes. Partial differential equations asserting conservation of mass, momentum, and energy are solved in each control volume to predict the development of the thermal flow field. The majority of the computational research to examine tank farm fires has been conducted using Fire Dynamics simulator (FDS) which is a CFD model developed by the National Institute of Standards and Technology (NIST). Zhou examined the impact of different wind configurations on the heat fluxes to an adjacent tank in a tank farm (diameter 80 m, height 22 m, separation 32 m) exposed to a crude oil fire [19]. Rengel et al. used FDS to recreate medium and large scale experiments of gasoline and diesel fuel tank fires [20]. Researchers have used other tools such as Ansys CFX [21], Ansys Fluent [22], FLACS [20].

While each of these approaches can provide estimates for many scenarios, the specific fire dynamics observed in the fires at ITC were different than a typical tank farm fire. This difference is outlined in Section 3.3.

A-3.3. ITC DEER PARK FIRE SCENARIO

Prescriptive and performance-based assessment of liquid tank fires are based on pool fire relationships. The mass evaporation rate of fuel in a pool fire is a function of the heat transfer to the surface and the latent heat of vaporization of the fuel. In a typical pool fire, the primary combustion reaction occurs directly above the liquid surface, as shown on the left in Figure A-7. The flame radiates heat to the surface which leads to an increased evaporation rate of the fuel. This feedback mechanism leads to a steady state evaporation rate where the heat flux from the flame is balanced by the latent and sensible heat losses from the surface. However, in the ITC fire the evaporated fuel was exiting the top of the tank through vertical pressure release vents, leading to a horizontal jet flame exiting the tank, as shown schematically in the right of Figure A-7. As a result, the heat transfer to the liquid surface is primarily due to heat transfer from hot gases in the vapor space above the floating roof in the tank rather than radiation from the flame. In addition, the tanks involved in the ITC fire were equipped with floating roofs designed to reduce the surface available for evaporation. Assuming the floating roofs function as intended, pool fire relationships based on the diameter of the tank will significantly overestimate the total heat release rate of the fire.

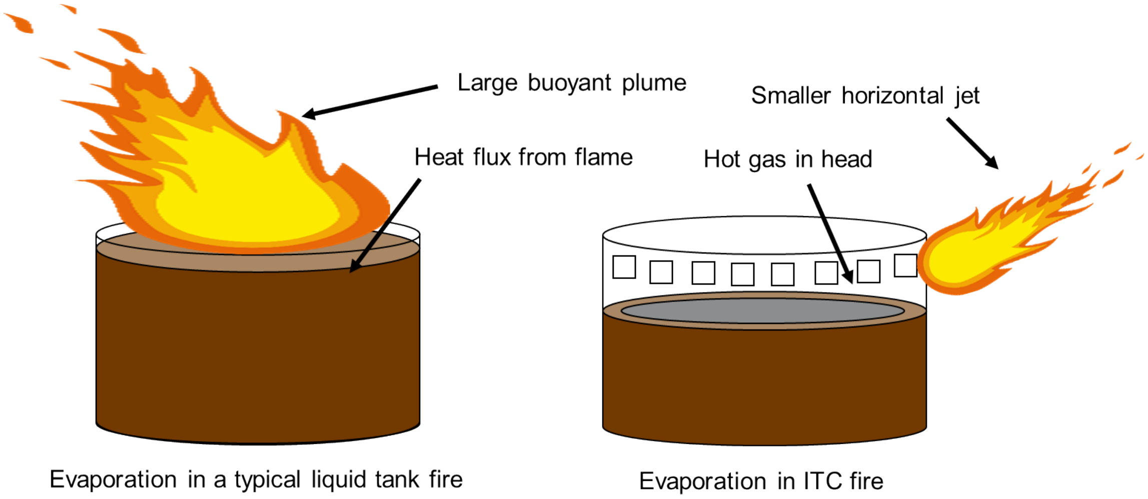


Figure A-7. Comparison of typical liquid fuel tank fire and ITC Deer Park, TX fire.

A-4.0 Fire Modeling

This work focused on modeling the fire dynamics observed in the ITC fire to better understand the tank-to-tank fire spread. The objectives of this analysis were the following:

1. Evaluate the tank-to-tank thermal exposure considering uncertainties in wind conditions, geometric configuration, fuel type, and fire size.
2. Evaluate the additive impact of pool fires at the grade level on tank exposure.
3. Evaluate the efficiency of tank spacing requirements in NFPA 30.

The fire modeling was conducted in three phases. The focus of each phase was the following:

1. Hand calculations to predict liquid evaporation rate in ITC Deer Park, TX configuration.
2. Hand calculations to predict thermal exposure (heat flux) versus distance in ITC Deer Park, TX configuration.
3. Detailed computational fluid dynamics (CFD) model to predict heat flux versus distance in ITC Deer Park, TX configuration.

A-4.1. HAND CALCULATIONS TO PREDICT LIQUID EVAPORATION RATE IN TANK

The focus of this phase of the analysis was to determine a realistic estimate of the fuel evaporation rate within the tank during the ITC fire. Several fundamental concepts related to this modeling effort are summarized below:

- The evaporation rate depends on the net rate of heat transfer and heat of vaporization of the fuel.
- The exposure heat transfer in the ITC fire is based primarily on the gas temperature in the head of the tank.
- Some of the incident radiation from the hot gas is transmitted through the surface of the fuel and absorbed through the depth of the fuel, based on the absorption coefficient of the liquid.
- Researchers have shown that the surface temperature of liquid fuels during steady burning is maintained at the boiling temperature of the liquid, as shown in Figure A-8.
- A hot zone can develop over time in a storage tank fire (especially in fires involved imperfect mixtures such as crude oil), where more of the fuel is at the boiling temperature, as shown in Figure A-9.

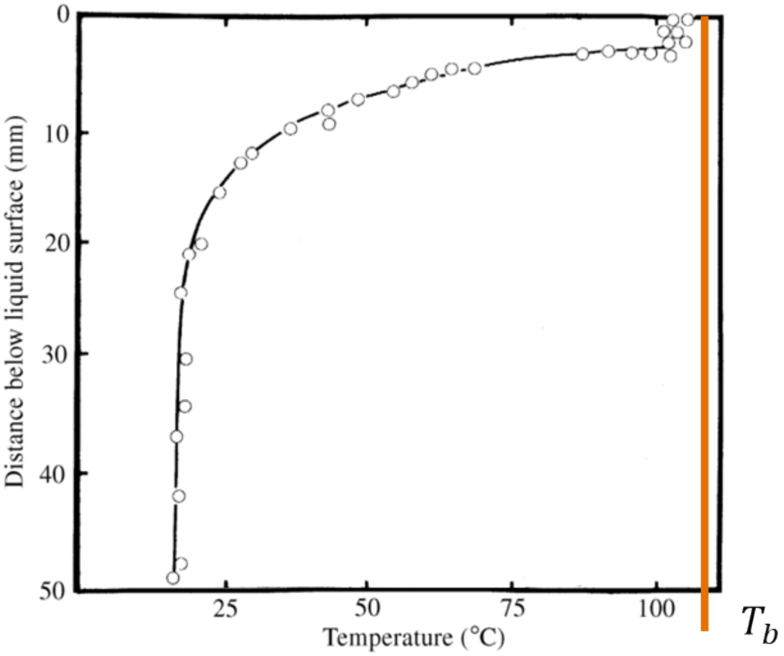


Figure A-8. Temperature distribution through the depth of a liquid pool fire during steady burning [23], [24].

After some period of transience, the liquid fuel will reach a steady burning period where the net energy being absorbed by the liquid equals the latent heat lost to evaporation. A one-dimensional heat transfer model was developed to predict the temperature distribution within the tank over time to understand the time required to reach this steady state.

The fundamental formulation of the model is based on the 1-D heat equation as formulated by Girgis et al. [25] for thermal stratification of stagnant lakes, where the radiant energy absorbed through the depth of the liquid is modeled as an internal generation term,

$$\frac{\partial T(z,t)}{\partial t} = \alpha \frac{\partial^2 T}{\partial z^2} + \frac{H(z,t)}{\rho c_p} \tag{3}$$

where T is the temperature of the liquid in the tank, z is the vertical position in the tank, t is time, α is the thermal diffusivity of the liquid, ρ is the density of the liquid, c_p is the specific heat capacity of the liquid, and H is the rate of heat generated per unit volume by internal absorption of radiation transmitted through the surface of the liquid. The internal absorption of radiation is calculated using the equation

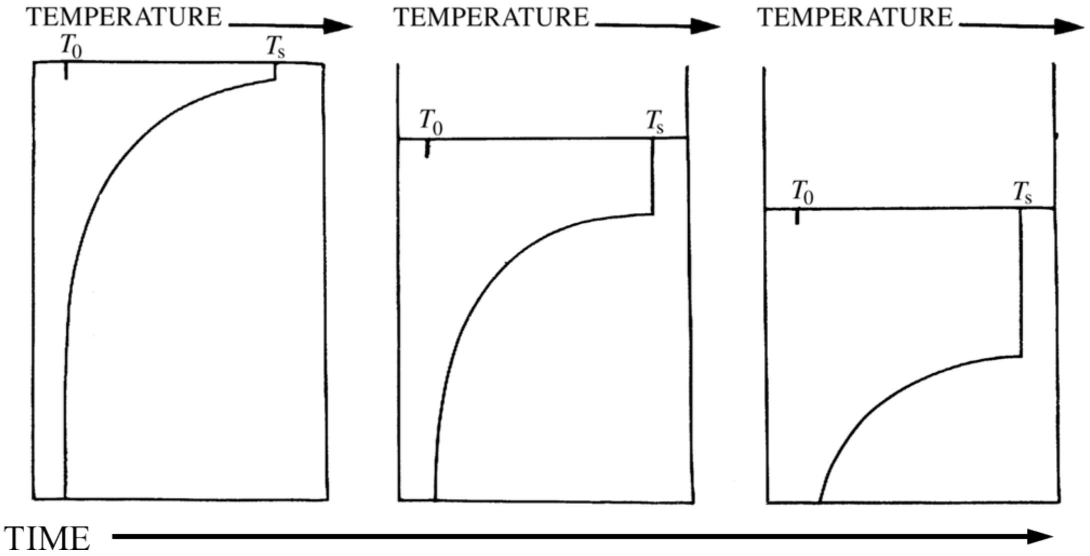


Figure A-9. Schematic showing the progression of a hot zone in a storage tank fire [24].

$$H(z,t) = \frac{\partial q''_{ab}}{\partial z} = q''_{inc}(t)(1-\beta)\kappa \exp(-\kappa\, z) \tag{4}$$

where q''_{inc} is the incident radiation on the surface, β is the fraction of energy absorbed at the surface, and κ is the absorption coefficient of the liquid. The incident radiation on the surface is calculated as

$$q''_{inc}(t) = \varepsilon_{gas}\sigma T_{gas}(t)^4 \tag{5}$$

where ε_{gas} is the gas emissivity (assumed to be 1.0 in this analysis), σ is the Stefan-Boltzmann constant, and T_{gas} is the gas temperature in the tank head in Kelvin. While the analytical formulation supports time-varying radiant exposure, a fixed value of gas temperature was used in this analysis. A mixed boundary condition was used at the surface of the liquid, defined as

$$\left(\frac{\partial T}{\partial z}\right)_{z=0} = [\beta q''_{inc}(t) + h\,(T_{gas}(t) - T(0,t)) - \varepsilon_l \sigma T(0,t)^4]\,(\rho c_p\,\alpha)^{-1} \tag{6}$$

where ε_l is the emissivity of the liquid surface (assumed to be 1.0 in this analysis). An adiabatic boundary condition was used at the bottom of the tank.

The assumptions made in the liquid tank model developed in this work are summarized below:

- The tank is large with a uniform exposure. Thus, there is an adiabatic boundary in the radial direction and the model only needs to calculate heat transfer in the vertical direction.
- The floating pontoon prevents evaporation of fuel, effectively reducing the exposed area.
- The tank is large relative to the evaporation of the fuel. Thus, the regression rate of the liquid surface can be neglected. This is believed to be reasonable based on the small fraction of liquid area not covered by the floating pontoon.
- The liquid fuel is stagnant. Thus, the convective motion of the fluid and the impact of eddy viscosity and turbulent diffusion can be neglected.
- The head of the tank is saturated with vaporized fuel. Thus, the evaporation rate of fuel is equal to the rate fuel leaves the tank.
- Incident radiation is partially absorbed at the surface ($\beta = 0.5$ in this analysis), and the remainder is absorbed through the depth of the fuel based on the absorption coefficient of the liquid.
- The maximum temperature the liquid can reach is its boiling temperature. Any energy absorbed by a control volume of liquid after reaching the boiling temperature goes to vaporizing fuel at the surface.

Equations 3-6 were solved numerically using an implicit finite difference scheme. A timestep of 0.01 s was used along with a grid size of 3 cm. The transient simulation was conducted for 2 hours of constant exposure with a head temperature 500 °C. Liquid properties in this analysis were based on petroleum-naphtha ($T_{boil} = 97.2℃$ [26], $L_v = 340\ kJ/kg$ [26]) which is representative of the liquid fuel in the initial tank involved in the ITC fire (Tank 80-8). Some properties were not available for petroleum-naphtha and n-heptane was used as a surrogate ($\kappa = 18.3\ atm^{-1}m^{-1}$ [27], $\Delta H_c = 44{,}400\ kJ/kg$ [28], $\rho = 688\ kg/m^3$ [28], $c_p = 2.2\ kJ/kg-℃$ [28], $k = 0.14\ W/m-K$ [29]). Transient temperature profiles within a liquid tank of petroleum-naphtha exposed to a 500 °C head temperature are shown in Figure A-10, and the corresponding transient evaporation flux is shown in Figure A- 11.

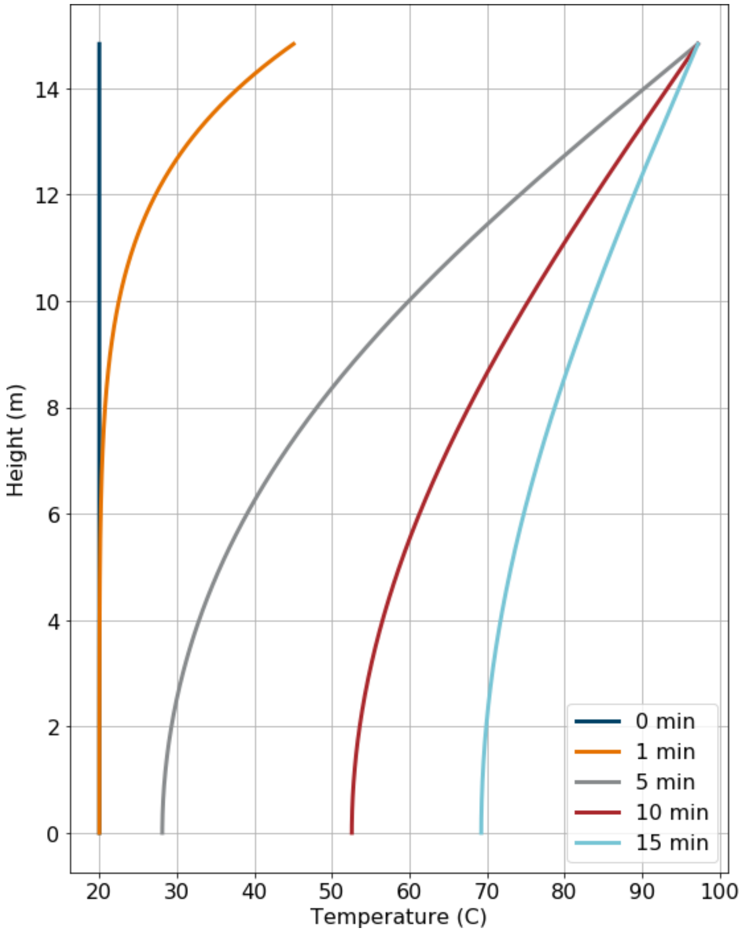


Figure A-10. Transient temperature profile in liquid tank of petroleum-naphtha exposed to 500 °C gas temperature.

Figure A-11 shows there is an initial spike in evaporation flux after 5 minutes of exposure, corresponding to the surface reaching the boiling temperature. The majority of the energy is absorbed at the surface due to the high absorption coefficient of the liquid, which results in the initial spike in evaporation flux nearly reaching the steady state value. The evaporation flux starts to rise after approximately 60 minutes of exposure as lower sections of the tank start to reach the boiling temperature. The time to reach the steady state evaporation flux is visualized in Figure A-12 by examining the time for the bottom of the tank to reach the boiling temperature. These results indicate that the liquid evaporation flux in the ITC fire likely reached a steady configuration within two hours of initiation.

The steady state evaporation flux was calculated for a range of head temperatures and fuel types and converted to a steady state heat release rate per unit of exposed area, as shown in Figure A-13. The corresponding total heat release rate of the tank based on an exposed area of 20.6 m^2 (221.7 ft^2) is shown in Figure A-14. A head temperature of 500 °C exposes the liquid to a similar heat flux as a flame above the surface (20 kW/m^2). These results indicate the total heat release rate for one tank in the ITC Deer Park, TX fire would be 63.22 MW for a

500 °C exposure. This yields a per vent heat release rate of 2.4 MW for 26 uniform vents. The flame length predicted based on a 2.4 MW fire (see phase 2 analysis, Eq. 7) agreed well with the flame extension observed in the ITC fire. These results were used as a baseline configuration for the analysis in the hand calculations and detailed CFD modeling.

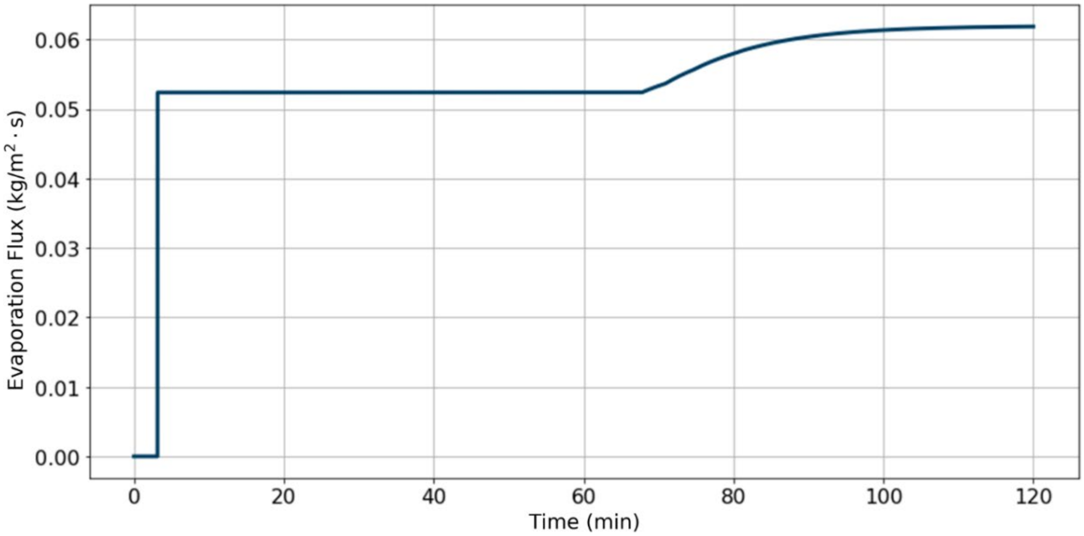


Figure A-11. Transient evaporation flux in liquid tank of petroleum-naphtha exposed to 500 °C gas.

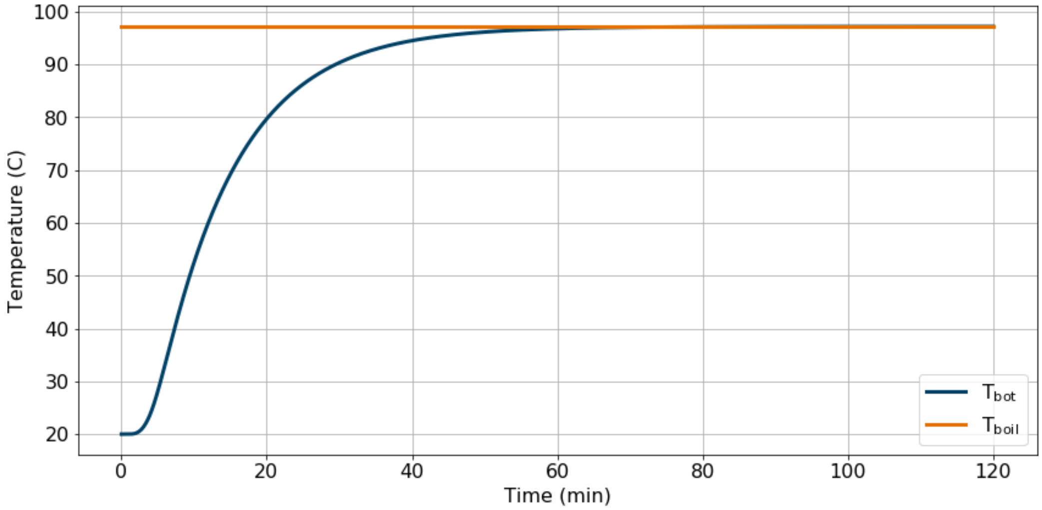


Figure A-12. Transient temperature at bottom of liquid tank of petroleum-naphtha exposed to 500 °C gas.

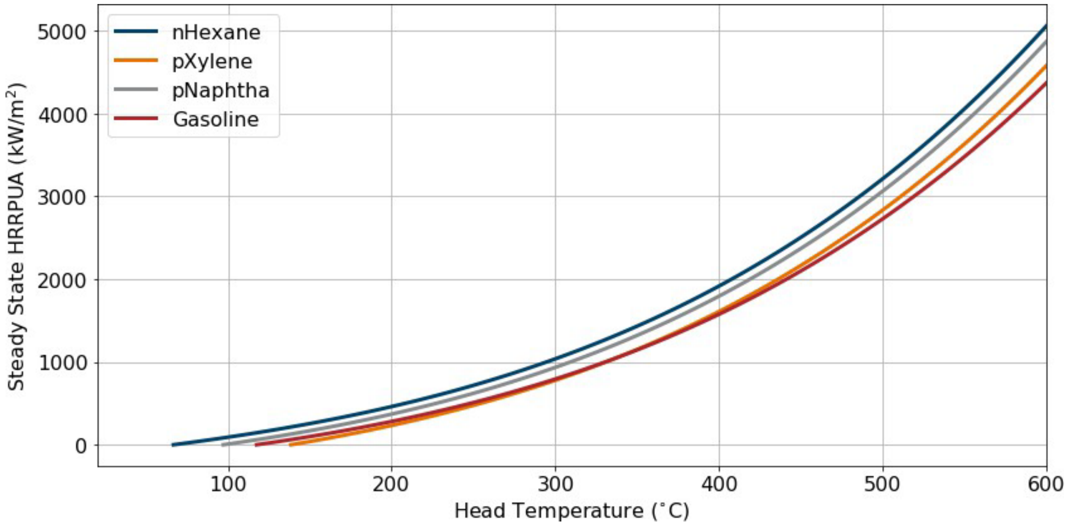


Figure A-13. Steady state heat release rate per unit exposed area versus head temperature for different fuels.

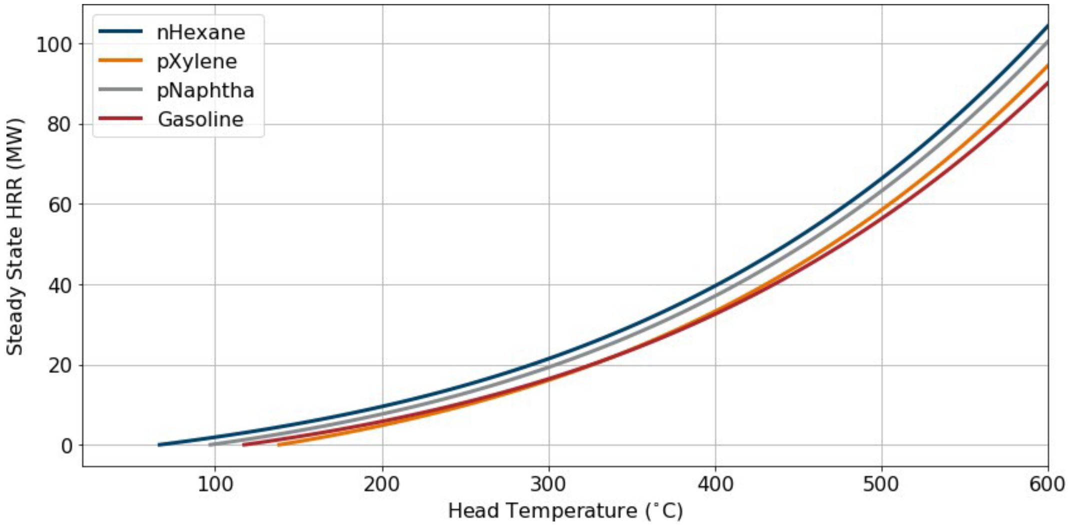


Figure A-14. Steady state total tank heat release rate versus head temperature for different fuels.

A-4.2. HAND CALCULATIONS TO PREDICT THERMAL EXPOSURE VERSUS DISTANCE

The focus of this phase of the analysis was to determine a realistic estimate of thermal exposure from the ITC fire with different separation distances using engineering hand calculations. Hand calculations were conducted using two models: the tilted point source [18], and the Mudan model [17]. The fundamental assumptions related to this modeling effort are summarized below:

- The evaporated fuel exits the side of the tank at several vent locations along the outer rim of the tank ($N_{vents} = 26$ in this analysis).
- The evaporated fuel is evenly distributed among the vents.
- The heat flux to the adjacent tank is a linear combination of the heat flux contribution from the fire at each vent.
- Tilting of the flame behaves similarly to a typical pool fire tilted by wind.
- Shortening of flame resulting from increased wind (due to increase in mixing near tank) neglected.

The tilted point source model was based on the modification presented by Sengupta [18] to incorporate the impact of wind. However, rather than placing the base of the fire at the center of the tank, the fire was split into N_{vents} sections, evenly distributed along the rim of the tank. A schematic of the representation is shown in Figure

A-15. Heat flux contributions from all vents in the front 180 degrees of the burning tank were considered in this analysis.

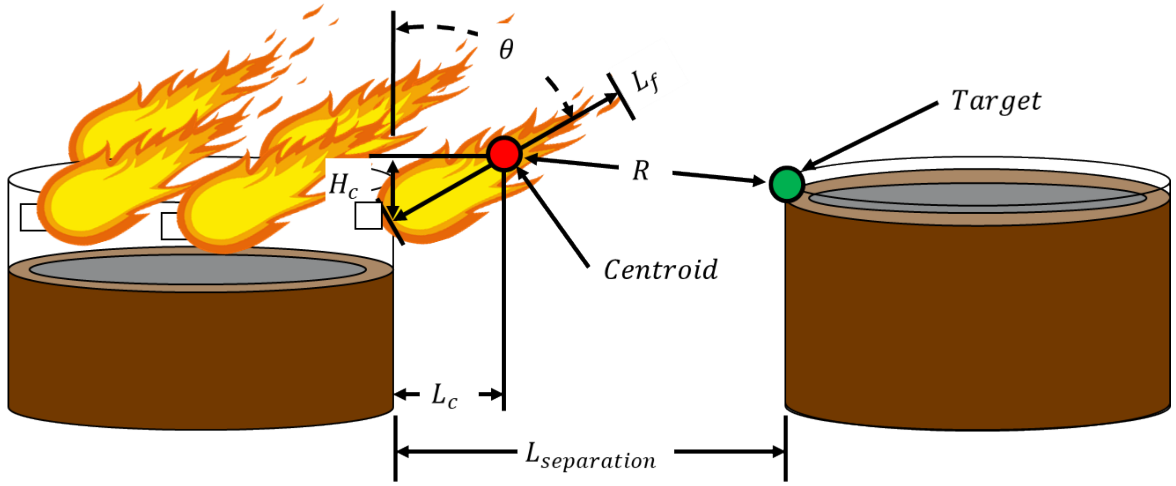


Figure A-15. Schematic representation of tilted point source hand calculation.

The flame length was calculated using Heskestad's correlation for flame length in a no wind configuration [30],

$$L_f = 0.235 Q_{vent}^{2/5} - 1.02 D_{vent} \tag{7}$$

where L_f is the flame length, Q_{vent} is the per vent heat release rate, and D_{vent} is the equal area diameter of the vent. The height and width of the flame centroid was calculated using trigonometry,

$$H_c = \frac{L_f}{2}\cos(\theta) \tag{8}$$

$$L_c = \frac{L_f}{2}\sin(\theta) \tag{9}$$

where H_c is the height of the centroid, L_c is the length of the centroid, and θ is the flame tilt angle measured from vertical. The flame tilt angle was calculated using the Muñoz et al. correlation [31],

$$\theta = \begin{matrix} \cos^{-1}(0.96u^{*,-0.26}) \\ 0 \end{matrix} \quad \text{for} \quad \begin{matrix} u^* \geq 1 \\ u^* < 1 \end{matrix} \tag{10}$$

where u^* is non-dimensional velocity,

$$u^* = \frac{u_w}{u_c} = \frac{u_w}{(g\dot{m}''_{vent} D_{vent}/\rho_a)^{1/3}} \tag{11}$$

where u_w is the wind velocity, u_c is the fire plume velocity, g is the acceleration due to gravity, $\dot{m}''_{vent}$ is the mass burning rate at a single vent, and ρ_a is the ambient air density. The linear distance from the flame centroid to the target on the adjacent tank was calculated based on trigonometry,

$$R = [L^2 + H_c^2]^{1/2} \tag{12}$$

where R is the linear distance to the target on the adjacent tank, and L is the horizontal distance between the centroid and the target. The horizontal distance between the centroid and the target for a specific vent was calculated using trigonometry,

$$L = ([L_{separation} - L_c + D_{tank}(1 - 0.5\cos\psi)]^2 + [0.5 D_{tank}\sin\psi]^2)^{1/2} \tag{13}$$

where D_{tank} is the diameter of the tank, and ψ is the angle of the vent off the centerline of the tank. The heat flux to the target is calculated using the point source model,

$$\dot{q}''_{gauge} = \frac{\chi_r \dot{Q}_{vent}}{4\pi R^2}\frac{L}{R} \tag{14}$$

where $\dot{q}''_{gauge}$ is the heat flux, and χ_r is the radiative fraction.

It is worth noting that χ_r in this context is not purely a property of the chemical reaction. By definition, it is the percentage of the total energy released by the fire which is transmitted to boundaries through radiation. For smaller fires typically observed in a laboratory setting, χ_r typically ranges from 0.3 to 0.4. However, the thick layer of soot generated in large pools absorbs a significant fraction of the radiant energy emitted by flames near the center of the pool, resulting in more of the energy being lost to the convective transport of the soot. Beyler presented a correlation to account for this phenomena [32],

$$\chi_r = 0.21 - 0.0034 D_{tank}. \tag{15}$$

Based on Eq. 15, $\chi_r = 0.1$ for the geometry examined in this work. However, this relationship is based on a large pool fire, and it is uncertain how valid this correlation is to the series of smaller fires on the rim observed in the ITC fire. For the hand calculations using this approach, a range of values for χ_r were considered to understand the impact of this parameter.

Heat fluxes with different separation distances and χ_r computed using the tilted point source model with a 10 mph wind speed are shown in Figure A-16. The safe separation distance threshold in this analysis is 8 kW/m^2 based on the heat flux required to ignite an adjacent tank. The heat fluxes predicted using the tilted point source model indicate that fire exiting the vents on Tank 80-8 would be well below the heat flux required to ignite an adjacent tank of 8 kW/m^2 regardless of the uncertainty in χ_r. Using Beyler's correlation for χ_r, the best estimate of the heat flux at the target position is 1.0 kW/m^2. Note, these results are prior to adding the recommended factor of safety multiplier of 2.0x.

The second hand calculation method conducted in this analysis used the method presented by Mudan [17]. In this approach, the point source is replaced with a titled cylinder. A schematic representation of the approach is shown in Figure A-17. The heat flux is calculated in this approach using the equation

$$\dot{q}'' = E F_{max} \tau \tag{16}$$

where E is the average emissive power at the flame surface, F_{max} is the view factor from the cylinder to the target, and τ is the transmissivity of the atmosphere. The average emissive power of the flame is given as the fractional average of the flame emissive power and smoke emissive power, by the equation

$$E = E_{max} \exp(-sD) + E_s[1 - \exp(-sD)] \tag{17}$$

where E_{max} is the equivalent blackbody emissive power (140 kW/m^2), s is the extinction coefficient (0.12 m^{-1}), E_s is the emissive power of smoke (20 kW/m^2), and D is the equivalent pool diameter. The equivalent pool diameter in Eq. 17 acts similar to χ_r in the point source model, effectively accounting for the fraction of energy which is lost due to convection of smoke. It is unclear whether basing the emissive power on D_{tank} or D_{vent} will provide a more realistic estimate due to the difference in fire dynamics. As the true emissive power is likely bounded between these two numbers, the analysis was performed both ways to provide a range of predicted values.

The view factor for the tilted cylinder was calculated using the equations presented by Beyler [14]. A more detailed discussion of the view factor calculation can be found in [14].

Beyler provides the atmospheric transmissivity as a function of relative humidity, ambient air temperature, and radiative path length [14], reproduced below in Figure A-18. A detailed discussion of the development of Figure A-18 can be found in [14]. Assuming the radiative path length is on the order of the tank separation (~11m) and a relative humidity of 40%, a value of 0.85 was used for τ in this analysis.

Heat fluxes with different separation distances and wind speeds computed using the tilted cylinder model assuming the effective diameter is the vent diameter and tank diameter are shown in Figure A-19 and Figure A-20, respectively. The heat fluxes predicted using the tilted cylinder model agree with the point source model, indicating that fire exiting the vents on Tank 80-8 would be well below the safe separation threshold of 8 kW/m^2

regardless of the uncertainty in the effective diameter. Using the vent diameter, the heat flux on the adjacent tank was predicted to be in the range from 3.0-3.5 kW/m^2 for different wind speeds. Using the tank diameter, the variation due to wind speed was negligible, with a predicted heat flux of 0.5 kW/m^2.

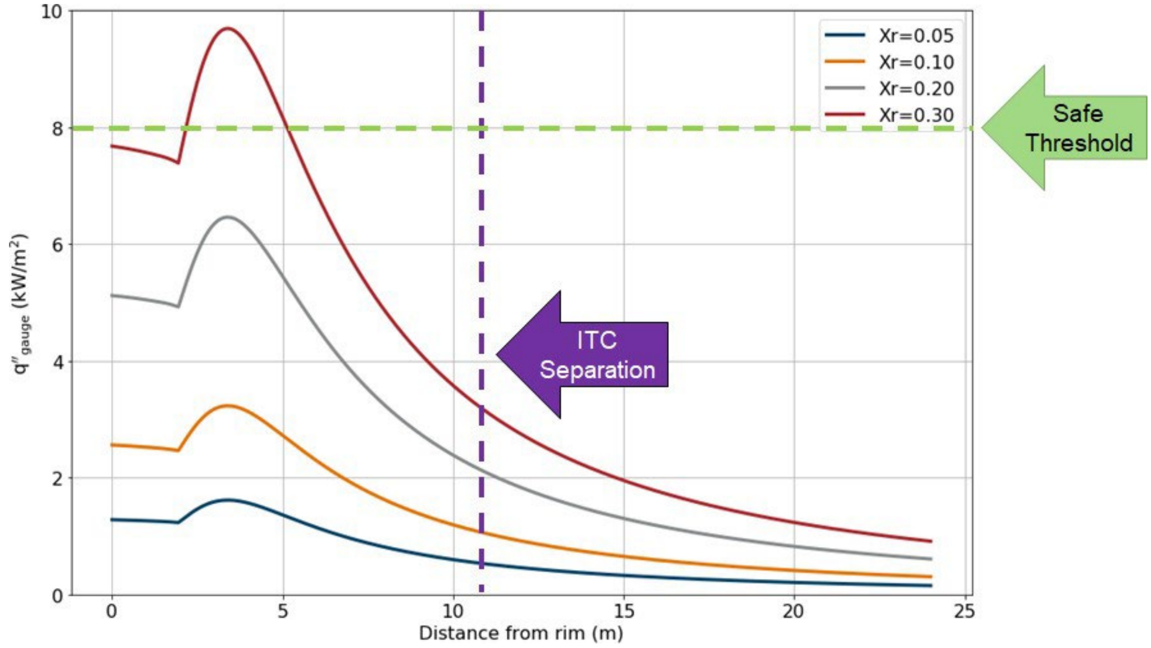


Figure A-16. Heat flux predictions using the titled point source model at different separation distances and χ_r.

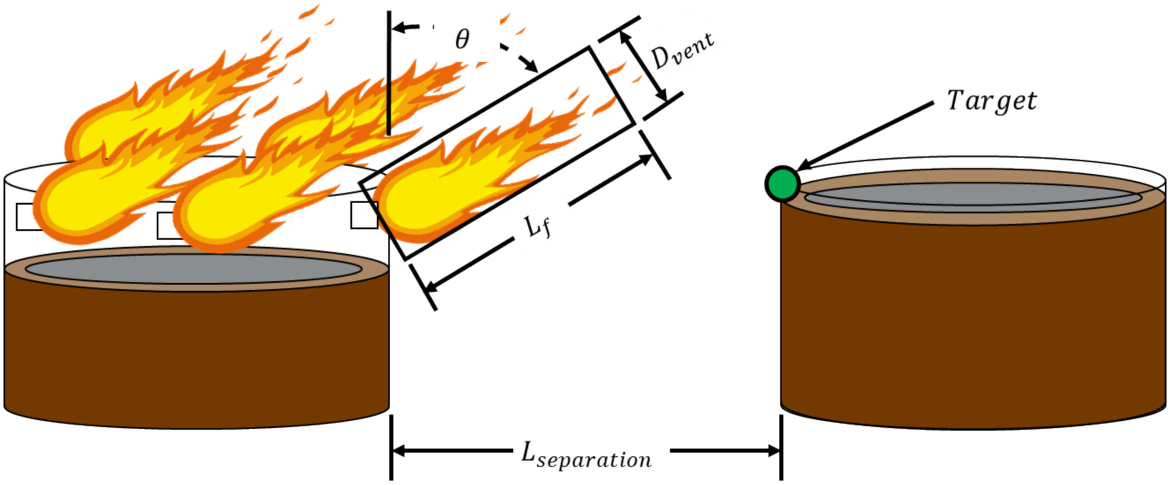


Figure A-17. Schematic representation of tilted cylinder hand calculation.

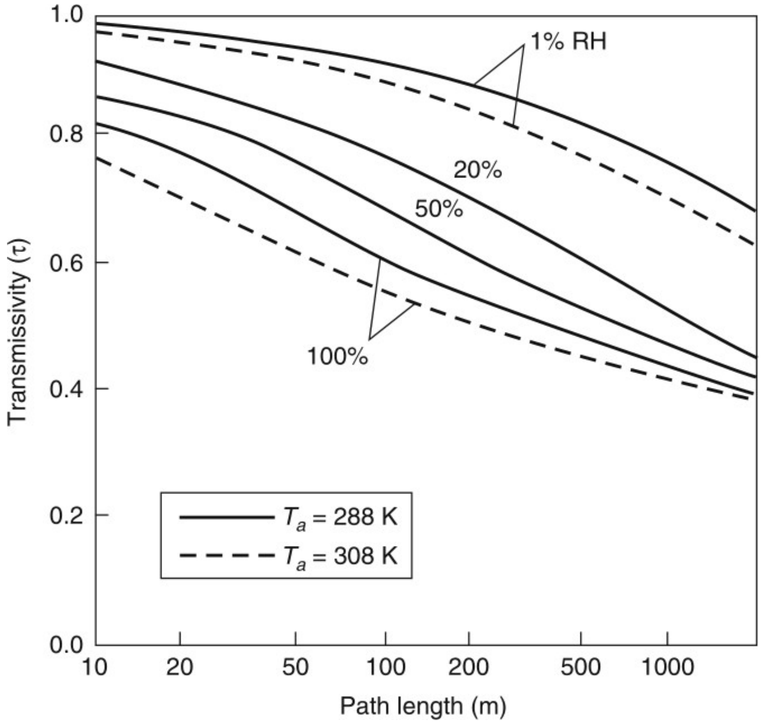


Figure A-18. Atmospheric transmissivity as a function of radiative path length, ambient air temperature, and relative humidity [14].

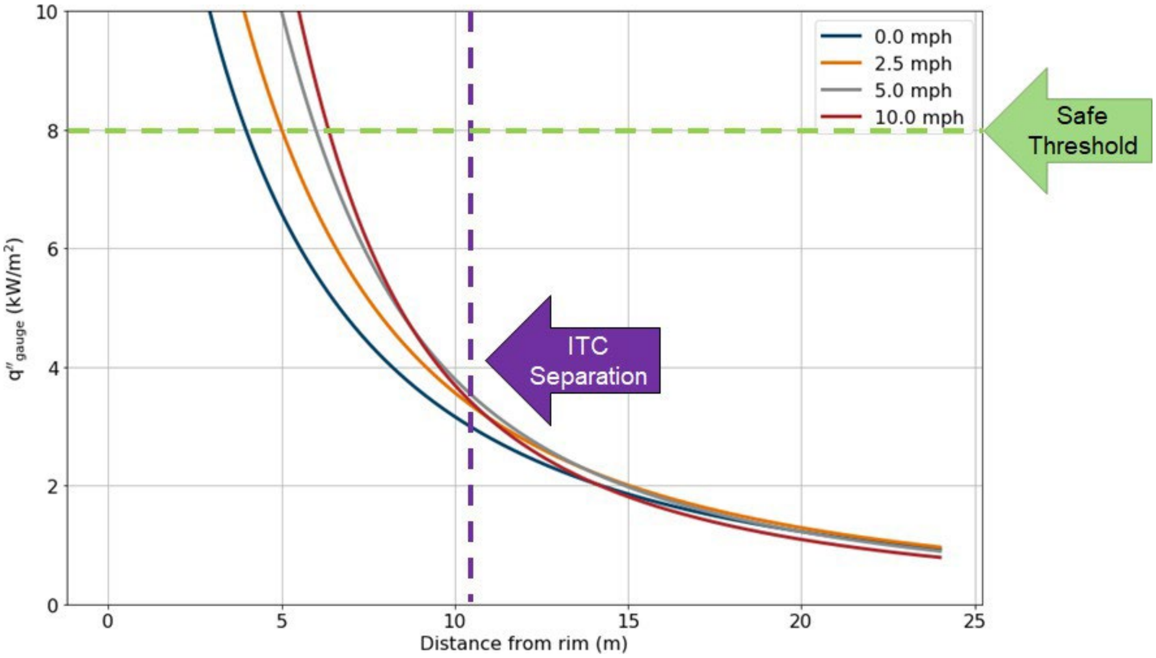


Figure A-19. Heat flux predictions using the titled cylinder model at different separation distances and wind speeds, assuming the effective diameter is the vent diameter.

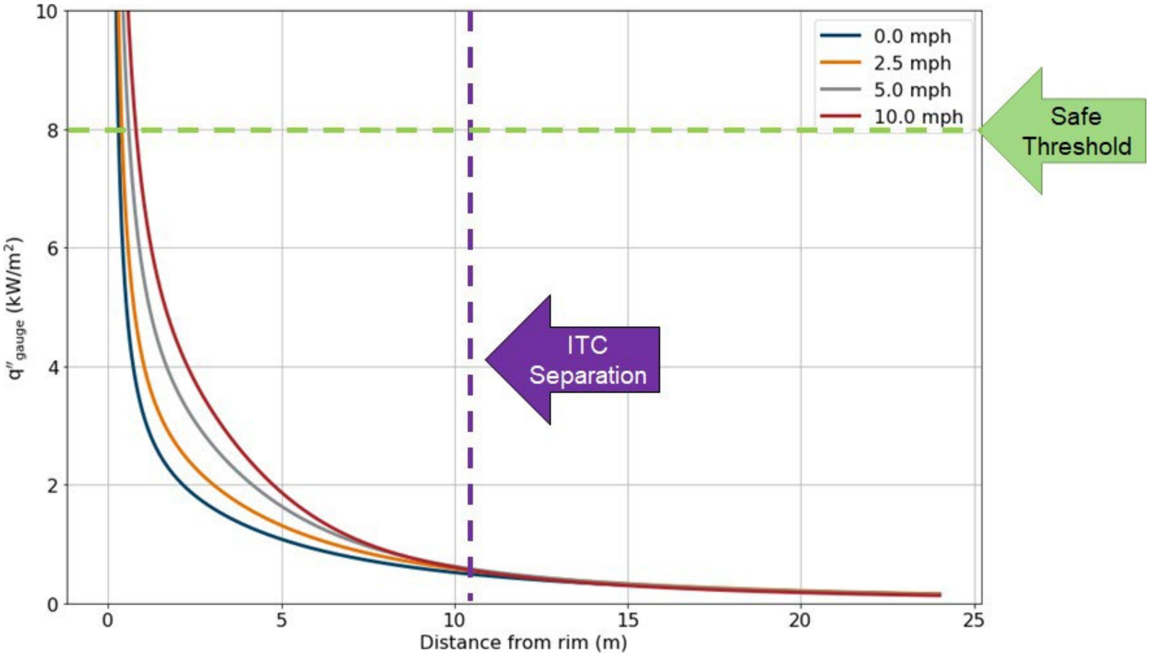


Figure A-20. Heat flux predictions using the titled cylinder model at different separation distances and wind speeds, assuming the effective diameter is the tank diameter.

A-4.3. DETAILED FIRE MODELING TO PREDICT THERMAL EXPOSURE

The focus of this phase of the analysis was to perform an assessment of the thermal exposure from the ITC fire using a highly resolved computational fluid dynamics (CFD) model to obtain a more realistic estimate of the exposure than can be achieved with engineering hand calculations. The simulations were conducted using Fire Dynamics Simulator (FDS, version 6.7.4) developed by the National Institute of Standards and Technology (NIST). The following sub-sections provide an overview of FDS, the specific fire scenarios modeled in this analysis, and a discussion of the model sensitivity and uncertainty.

OVERVIEW OF FIRE DYNAMICS SIMULATOR

Fire Dynamics Simulator (FDS) is a general purpose low-speed (Mach number < 0.3) computational fluid dynamics (CFD) software primarily designed to model buoyantly drive flows typical of diffusion flames [33], [34]. In an FDS simulation, the computational domain is divided into small (on the order of 10s of cm) control volumes (often called grid cells). By solving a set of partial differential equations asserting conservation of mass, momentum, and energy in each grid cell as well as a radiation transport equation, the software predicts the time-evolution of the gas temperature, velocities, and species concentrations in each grid cell as well as heat transfer to solid surfaces. FDS has an extensive validation basis in fire safety applications [35], and is considered the state-of-the-art in fire modeling for diffusion flames. An overview of the sub-models in FDS used in this analysis are summarized below.

Turbulence Model

Similar to other CFD software, FDS numerically solves the Navier-Stokes equations which are the set of partial differential equations for the transport of mass, momentum, and energy by a fluid acting as a continuum. In this context a continuum means that the fluid density is high enough that molecule-molecule interactions are not modeled by the equations outside of bulk physical quantities. Typically, FDS simulations are conducted using the large eddy simulation (LES) method. In this mode of operation, the grid cells are not small enough to fully resolve the diffusive fluxes of heat and mass on the grid. As a result, a subgrid model is needed to characterize the dissipation of energy from smaller eddies. The Deardorff subgrid turbulence model is the default turbulence model in FDS, which was selected due to the its agreement with full-scale experiments [33], [34]. This model was used in this analysis based on the strong validation basis in the FDS validation guide [36].

Radiation Transport

FDS solves an additional transport equation for gray gas radiation through an absorbing, emitting, but not scattering medium. The radiation transport equation is solved using a finite volume method similar to the convective transport equations. Each grid cell is discretized into a number of discrete radiation angles, with the total emission split among the different angles. The absorption along each angle is calculated based on the absorption coefficient in adjacent grid cells. The absorption coefficient is calculated based on species concentration and temperature using an external model, RadCal [37]. At the LES grid scales, the cell-averaged gas temperatures within the flaming regions are smeared due to the flame thickness (on the order of 0.1 cm) not being resolved. The fourth power dependence on temperature in the radiation emission leads to an underprediction in the radiant emission in the flaming regions. This underprediction is corrected using a corrective factor based on the reaction rate in a specific cell and a globally defined radiative fraction which is a property of the gas phase combustion reaction. The uncertainty in this correction is accounted for in the uncertainty assessment presented in the FDS validation guide [35].

Combustion Model

The combustion model used in this analysis was a single-step, mixing-controlled combustion. In this model, the reaction is assumed to occur infinitely fast, which means whenever gaseous fuel and oxygen are present in the same grid cell, they are assumed to react instantly until either the fuel is consumed or oxygen concentration in the cell reaches the lower flammability limit. The lower flammability limit is based on the limiting oxygen index concept discussed by Beyler [38]. FDS can be used to predict piloted and unpiloted ignition through the use of an autoignition temperature. Piloted ignition was used in this analysis.

Solid Boundaries

Solid boundaries in FDS are handled using a simple immersed boundary method. A subgrid model is needed to predict convection heat transfer since the boundary layer near the wall is not resolved. FDS contains a number of different correlations for computing the heat transfer coefficient to surfaces. The default approach used in FDS is to compute a natural and a forced convection heat transfer coefficient using flat plate heat transfer correlations where FDS picks the larger number of the two correlations. This model was used in this analysis.

Wind Model

The atmospheric boundary layer in this analysis was modeled using Monin-Obukhov similarity theory. Under this paradigm, the inlet wind profile is calculated based on a reference velocity and stability criterion. The wind profile with height is defined as

$$u_w(z) = \frac{u_*}{\kappa_c}\left[\ln\left(\frac{z}{z_0}\right) - \Psi\left(\frac{z}{L_o}\right)\right] \qquad (18)$$

where $u_w(z)$ is the wind speed as a function of height, κ_c is the Von Kármán constant (0.41), z_0 is the aerodynamic roughness length (1.0 in this analysis, appropriate for suburbs, villages, and forests [39]), z is the height, u_* is the friction velocity, L_o is the Obukhov length, and Ψ is the similarity function [40],

$$\Psi\left(\frac{z}{L}\right) = \begin{cases} -5\dfrac{z}{L} & L \geq 0 \\ 2\ln\left[\dfrac{1+\zeta}{2}\right] + \ln\left[\dfrac{1+\zeta^2}{2}\right] - 2\tan^{-1}(\zeta) + \dfrac{\pi}{2} & \text{for } L < 0 \end{cases} \qquad (19)$$

$$\zeta = \left(1 - \frac{16z}{L}\right)^{1/4} \qquad (20)$$

The friction velocity is calculated based on a specified reference velocity and reference height,

$$u_* = \frac{\kappa_c u_{ref}}{\ln(z_{ref}/z_0)} \tag{21}$$

where u_{ref} is the reference velocity, and z_{ref} is the reference height. In this analysis, u_{ref} was varied from 1.2 m/s (2.7 mph) to 6.7 m/s (15.0 mph) at a reference height of 10.0 m. The Obukhov length was fixed at 350 m in this analysis, corresponding to a buoyantly stable atmospheric boundary layer. The upstream wind profile was perturbed to trip a turbulent boundary layer by re-cycling the flow field downstream with a periodic boundary condition.

OVERVIEW OF BASELINE CONFIGURATION

The overall dimensions of the tank farm were approximately 137.2 m (450 ft) x 222.5 m (730 ft), consisting of three rows and five tanks of columns, as shown in Figure A-2. In this analysis, a three row x three column region centered on Tank 80-8 was included in the computational domain. It was decided to model a symmetric configuration so that the results could be used as general guidance to describe either westerly or northerly wind configurations.

The computational domain is visualized in Figure A-21. The overall computational domain was 460 m (1,509 ft) x 190 m (623 ft) x 80 m (262 ft). The tanks were centered on the shorter horizontal axis. The tanks were off-centered 90 m towards the windward boundary to allow the wind profile to more fully develop in the leeward direction prior to reaching the periodic boundary. Periodic boundary conditions were used on the vertical edges of the computational domain. A solid, adiabatic boundary condition was used on the bottom of the computational domain. A constant streamline boundary condition was used on the top of the computational domain.

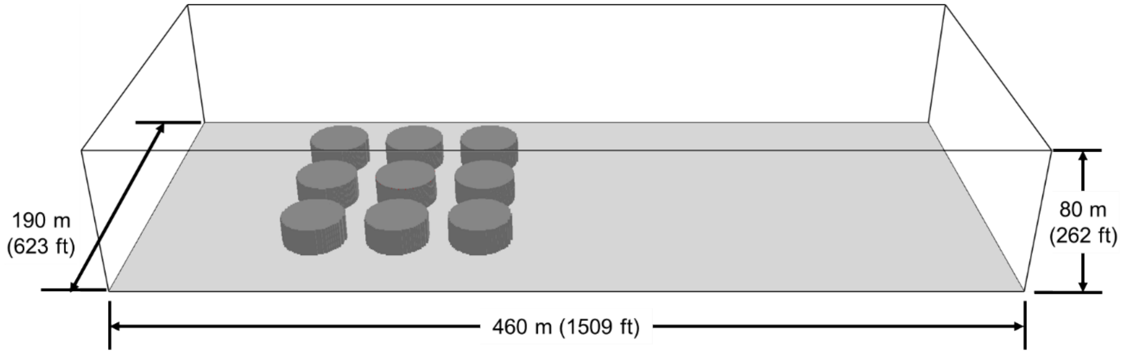


Figure A-21. Computational domain.

Using a fixed grid size across the entire computational domain was not feasible for this application (25 cm fixed grid would yield approximately 450 million grid cells). Hybrid meshing was used to reduce the number of grid cells, a visualization along the centerline of the domain is shown in Figure A-22. A grid size of 25 cm was used near the combustion reaction, encompassing the upper half of Tank 80-8 and the leeward tank and extending 5.0 m above the tanks (heights 8.0 m - 20.0 m). A grid size of 50 cm was used for a region extending 8.0 m beyond the finest mesh in all directions. A grid size of 100 cm was used for the rest of the computational domain, except the last 100 m at the leeward edge where a grid size of 200 cm was used. This meshing strategy resulted in approximately 10,185,000 grid cells. A sensitivity case which used 20 cm at the finest grid, and followed a similar hybrid strategy was simulated to verify this resolution was sufficient to achieve a grid independent solution. The mesh sensitivity configuration had approximately 20,029,000 grid cells.

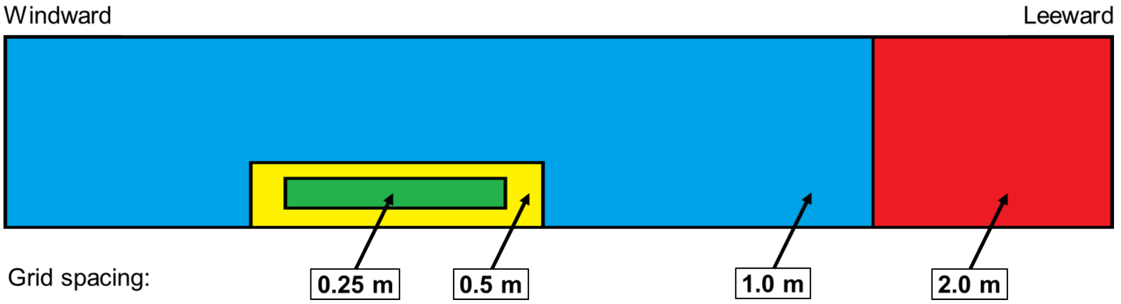


Figure A-22. Mesh resolution along centerline.

A total of 26 pressure release vents were applied at the top of the center tank, as shown in Figure A-23. The size of the vents was scaled to be 0.5 m (20 in) x 0.5 m (20 in) squares to align with the computational grid and provide four grid cells across the vent. The outlet temperature at the vent was fixed at 500 °C based on the interior head temperature. The total heat release rate for each vent was fixed at 2,431 kW (heat release rate per unit area = 9,725 kW/m^2) based on the liquid fuel evaporation rate found in the phase one analysis. The resulting overall heat release rate was 63.2 MW. The specified heat release rate was fixed throughout the entire simulation duration. A sensitivity case was simulated which included a 60 second lead in time for the wind flow field to initialize prior to ignition of the vents.

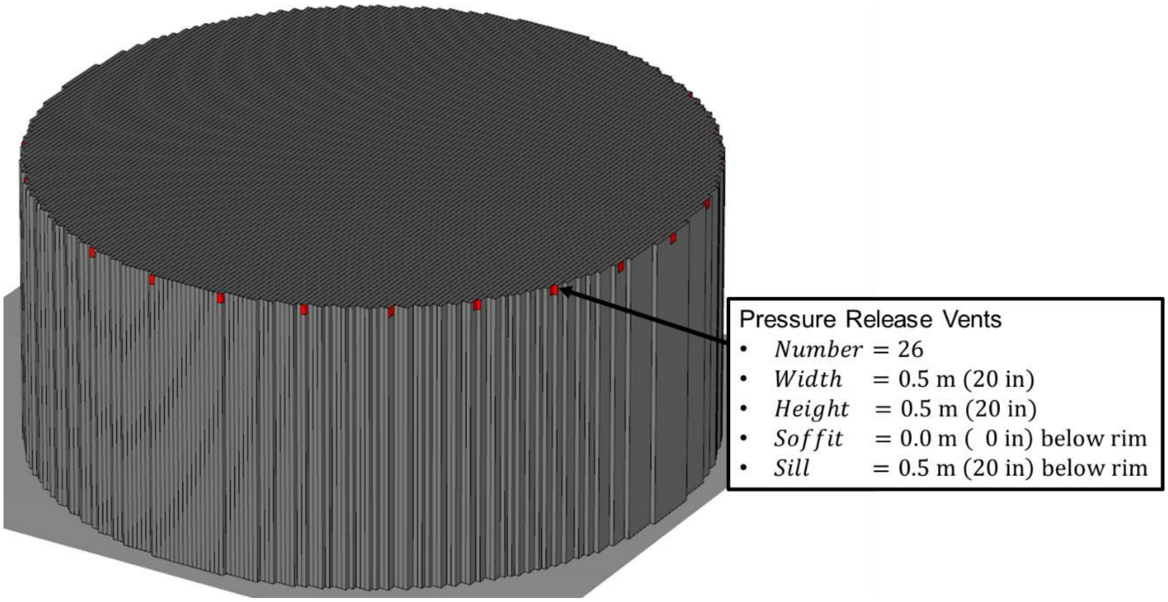


Figure A-23. Visualization of pressure release vents on Tank 80-8.

The gas phase combustion reaction was based on petroleum-naphtha ($C_{10}H_8$), with a normalized chemical formula of $CH_{0.8}$, soot yield of 0.175 (g/g), carbon monoxide yield of 0.065 (g/g), heat of combustion of 39,000 kJ/kg, and radiative fraction of 0.4256 [28]. The resolution on the radiation transport equation was increased to 360 angles from the FDS default of 100 based on the size of the computational domain. Two sensitivity cases were simulated with 180 and 540 angles to verify this resolution was sufficient.

Ambient conditions in the model represented a relative humidity of 40%, gas temperature of 20°C. The baseline configuration used a 10 m wind speed of 2.2 m/s (5 mph). Each simulation was run for 300 seconds of fire exposure to allow quasi steady state conditions to develop. The thermal exposure from the adjacent tank to the leeward tank was quantified using a gauge heat flux. The heat flux gauge had a fixed emissivity of 1.0 and temperature of 20°C.

Each simulation was run on a linux cluster on Amazon Web Service (AWS). All cases used 48 central processing units (CPUs) with 48 message passing interface (MPI) processes, except the fine grid sensitivity case which used 96 CPUs with 96 MPI processes. Computational time varied across the models, but was typically on the order of 5-6 days. Computational time for the fine grid sensitivity case was 8 days.

The transient development of the fire and smoke from the fire in Tank 80-8 is visualized in Figure A-24. The smoke profile generally stabilized after 180 seconds of exposure. The time-resolved thermal exposure at the peak location and the center on the windward side of the adjacent tank is shown in Figure A-25. These results show that the thermal exposure stabilizes to a quasi-steady state after approximately 60 seconds, although there is variability in the instantaneous thermal exposure (standard deviation from 60-300 seconds was 0.09 kW/m^2). The maximum time-averaged thermal exposure observed on the adjacent tank was 1.34 kW/m^2, occurring approximately 1 m (3.3 ft) below the rim of the tank. The spatial distribution of the time-averaged thermal exposure on the windward side of the adjacent tank is visualized in Figure A-26.

OVERVIEW OF UNCERTAINTY

It is important to understand the impact of uncertainty on the thermal exposure predictions made using the detailed CFD model. There are two main sources of uncertainty relevant to the analysis: Input parameter uncertainty, and Model uncertainty. The overall uncertainty in a CFD prediction is the combination of the input parameter uncertainty and model uncertainty.

Input parameter uncertainty is associated with factors that must be known about a scenario and provided to the model to make predictions. Some example input parameters in this analysis include the wind conditions, heat release rate of the fire, and details regarding the chemical reaction. In developing the baseline model of the ITC fire, we specified each of these parameters to the best of our ability based on available information. However, it is important to understand the impact of uncertainty in these estimates on the thermal exposure predicted by the model. One way to quantify this impact is to run additional simulations where the uncertain input parameters are varied and compare the results with the baseline simulation. Several additional simulations were conducted in this analysis to understand the impact of uncertainties in the wind conditions, fuel source, pressure release vent geometry, numerical discretization, and radiation transport on the predicted thermal exposure.

Model uncertainty on the other hand, is the potential error in model predictions when all the input parameters are well understood. This type of uncertainty is typically quantified by recreating carefully controlled experiments with the modeling software and comparing the predictions to the measurements. The FDS validation guide provides an extensive suite of experiments which have been gathered from the literature and reproduced using the software. The resulting model predictions are routinely compared with the experimental measurements to identify statistical bias and uncertainty in the predictions of specific quantities by FDS.

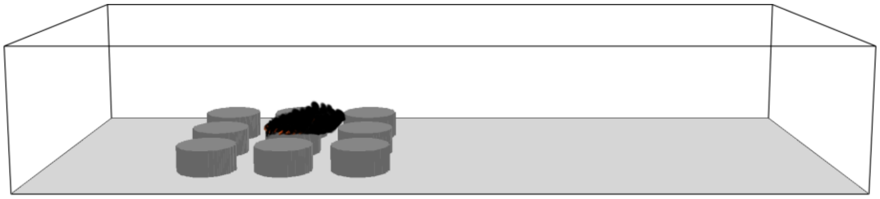
In this context, the bias represents the mean tendency of the model to over or under predict a specific quantity. Correcting for the model bias provides a best estimate of the true value. It is important to note that, by definition, the majority of simulations will agree well with experiments after correcting for the bias. However, there will always be some degree of scatter about the true value (outlier experiments which were not well predicted). The model uncertainty represents this degree of scatter about the true value.

The model bias and uncertainty in FDS is expressed in terms of a Gaussian distribution with a mean and sigma defined as,

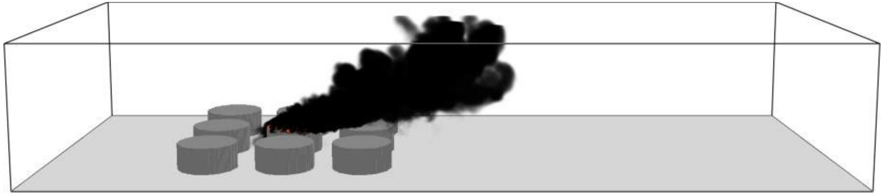
$$\mu = \frac{M}{\delta} \qquad (22)$$

$$\sigma = \sigma_M^2 \left(\frac{M}{\delta}\right)^2 \qquad (23)$$

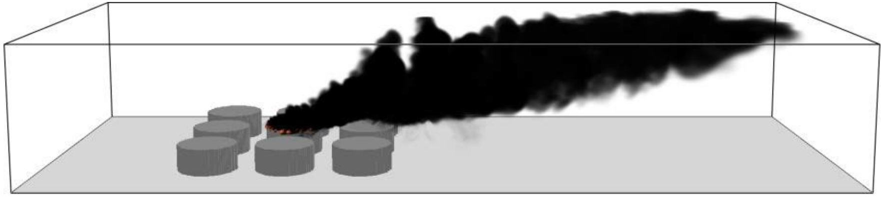
where M is the model predicted value, μ is the center of the distribution after correcting for the model bias, δ, σ is the standard deviation of the distribution, and σ_M is the model uncertainty. The FDS validation guide quantifies δ and σ_M for thermal exposure predictions to a target using FDS 6.7.4 is as 0.88 and 0.39, respectively.



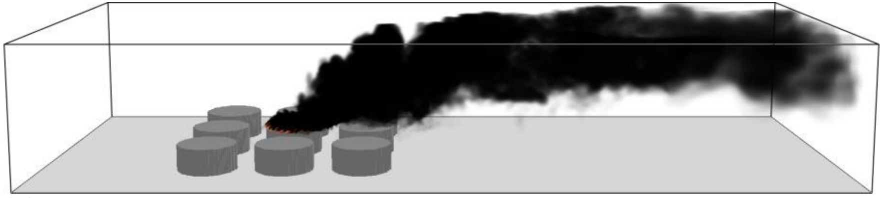
(a) t = 5 s



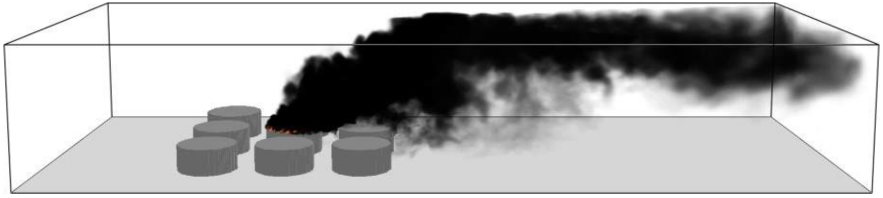
(b) t = 30 s



(c) t = 60 s



(d) t = 180 s



(e) t = 300 s

Figure A-24. Visualization of fire and smoke development in baseline model configuration.

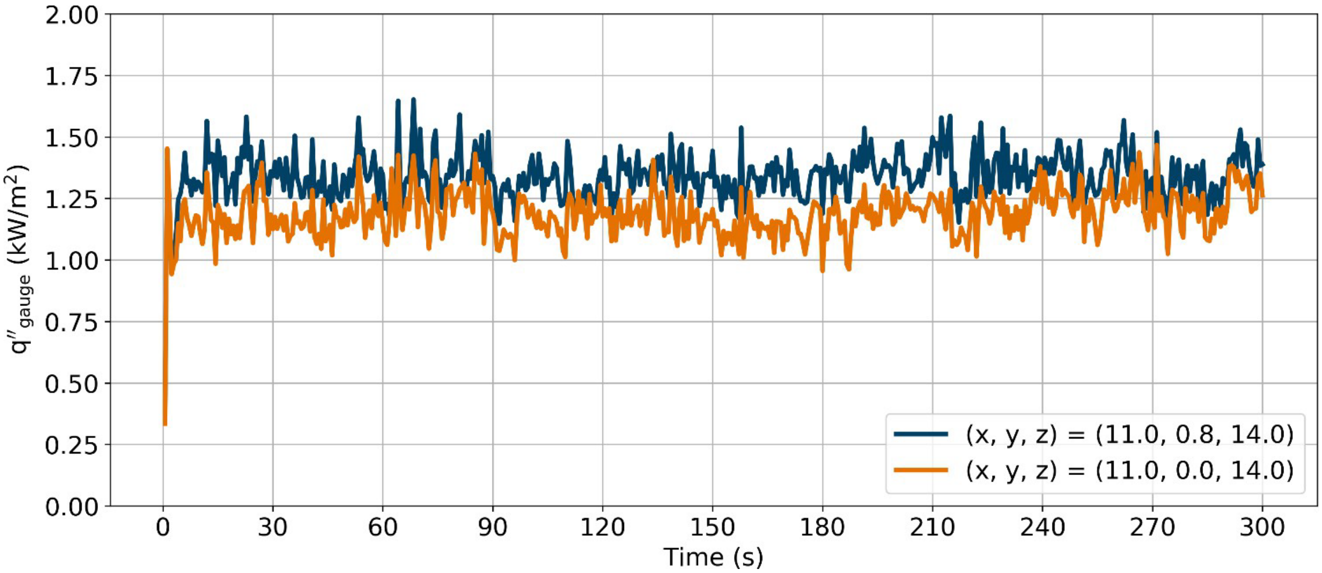


Figure A-25. Time resolved thermal exposure at peak location (blue) and at center of tank (orange) on windward side of adjacent tank.

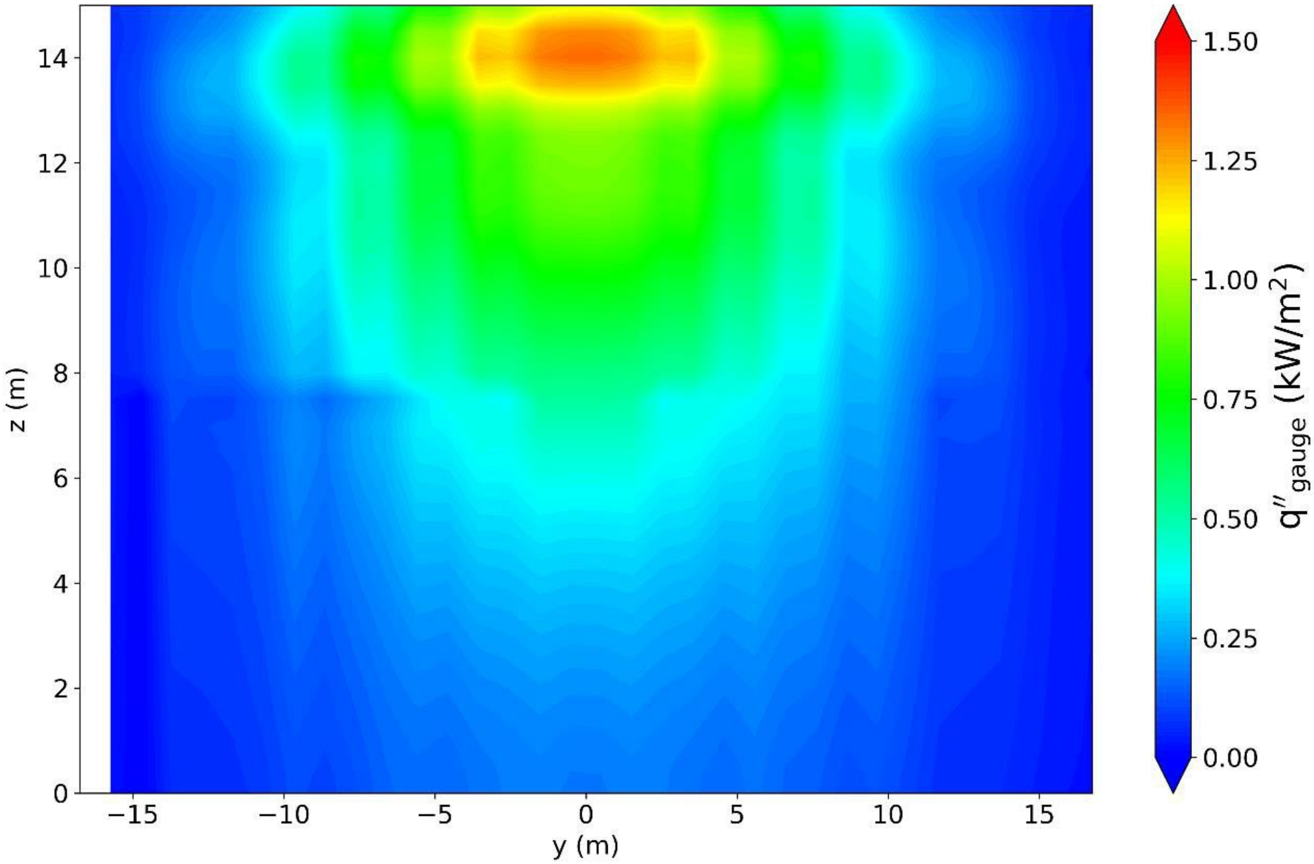


Figure A-26. Quasi steady state thermal exposure on windward side of adjacent tank.

This information is usually presented in terms of a probability density function (PDF) or cumulative distribution function (CDF), as shown for the peak thermal exposure on the windward wall of the adjacent tank in the baseline simulation in Figure A-27. The PDF shows the probability that the true thermal exposure is a specific value. The PDF in Figure A-27 shows that after accounting for the bias in the model, the actual best estimate of the thermal exposure is 12% higher at 1.52 kW/m^2 the raw model prediction of 1.34 kW/m^2. The CDF shows the probability that the true thermal exposure does not exceed a given value. This representation is often used in a risk assessment context where there is a need to design to a higher confidence, such as a 97.5th percentile (two standard deviations higher than the mean). For this higher degree of confidence in design, a thermal exposure of 2.23 kW/m^2 would be used. Considering our safe separation threshold of 8 kW/m^2, there is approximately a 1 in 1 quadrillion chance (10^{15}) that the model uncertainty would be sufficient to account for ignition of the second tank. Since a second tank did ignite, this implies that there is either significant uncertainty in the model inputs, or an additional heat source (such as a pool fire) which contributed to the ignition.

OVERVIEW OF SENSITIVITY ASSESSMENTS

Additional permutations of the baseline configuration were simulated to examine the sensitivity of the thermal exposure predictions to the grid discretization, simulation initialization, and the radiative path length.

Table A-1 summarizes the statistical differences between each sensitivity case and the baseline model configuration.

In CFD simulations it is important to verify that the grid resolution is resolved enough such that the solution is not dependent on the grid spacing. Figure A-28 compares the quasi steady state thermal exposure on the adjacent tank using the baseline mesh configuration (minimum grid size of 25 cm) and a more resolved mesh configuration (minimum grid size of 20 cm). These results indicate the spatial resolution in the baseline configuration is sufficient for this application, with the difference in peak exposure 1.5% and a root mean square error (RMSE) of 0.023 kW/m^2.

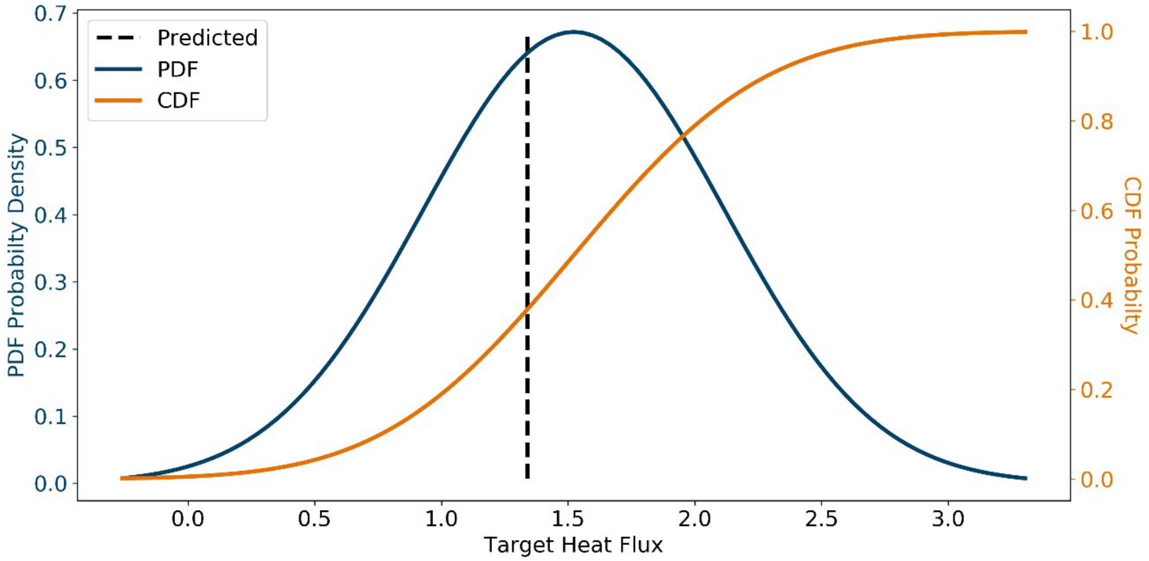


Figure A-27. Uncertainty in peak thermal exposure on windward wall of adjacent tank in baseline FDS model.

Table A-1. Statistical comparison of sensitivity cases. (*) denotes the model predictions were scaled by a factor of 2 prior to comparison with the baseline.

Scenario	$\bar{q}''_{gauge,max}$ (kW/m^2)	$RMSE$ (kW/m^2)
Baseline	1.34	-
Grid Independence ($\Delta = 20$ cm)	1.36	0.023
Initialization (60 seconds with wind without fire)	1.32	0.006
Radiation Angles (Coarse - 180 angles)	1.46	0.060
Radiation Angles (Fine - 540 angles)	1.27	0.021
Radiation Path Length (Larger – 1.0 m)	2.75	0.552
*Radiation Path Length (Larger – 1.0 m)	1.37	0.086

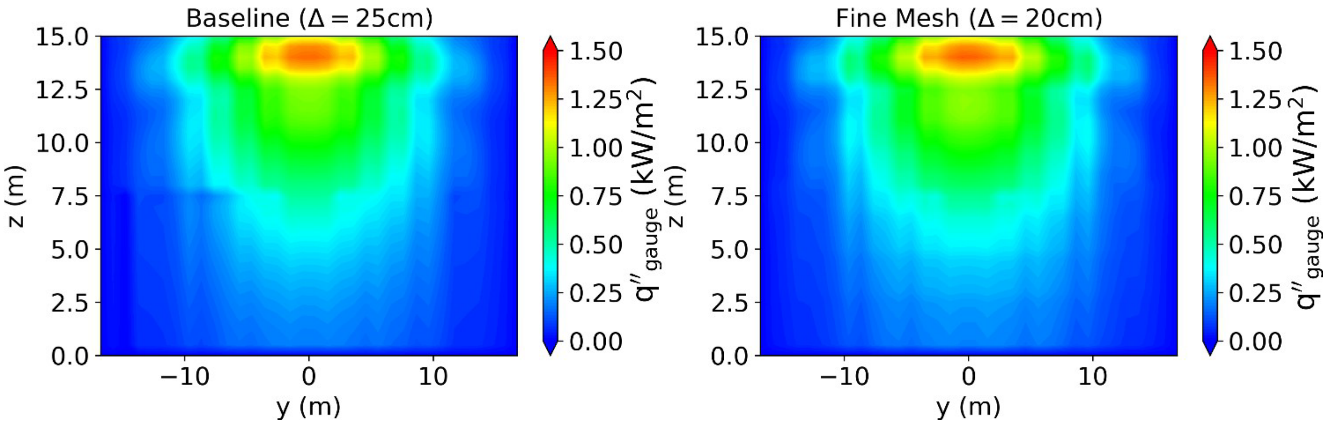


Figure A-28. Sensitivity assessment of grid resolution on quasi steady state thermal exposure on adjacent tank.

By default, FDS uses a fairly coarse discretization of the unit sphere in the radiation transport equation (100 angles). While this is sufficient for many applications in smaller domains, more angles are needed in this application due to the large spacing between tanks. Figure A-29 compares the quasi steady state thermal exposure on the adjacent tank using the baseline radiation angles used in this analysis (360) with less angles (180) and more angles (540) to verify the convergence of the angular discretization. These sensitivity results show that the peak thermal exposure decreases with more radiation angles due to the same amount of energy being distributed into more rays. This results in a less extreme peak, but a smoother distribution in radiant intensity across the tank. These results indicate the angular discretization in the baseline configuration is sufficient for this application, with the difference in peak exposure 5.2% and a RMSE of 0.021 kW/m^2 when compared with the 540 angles configuration.

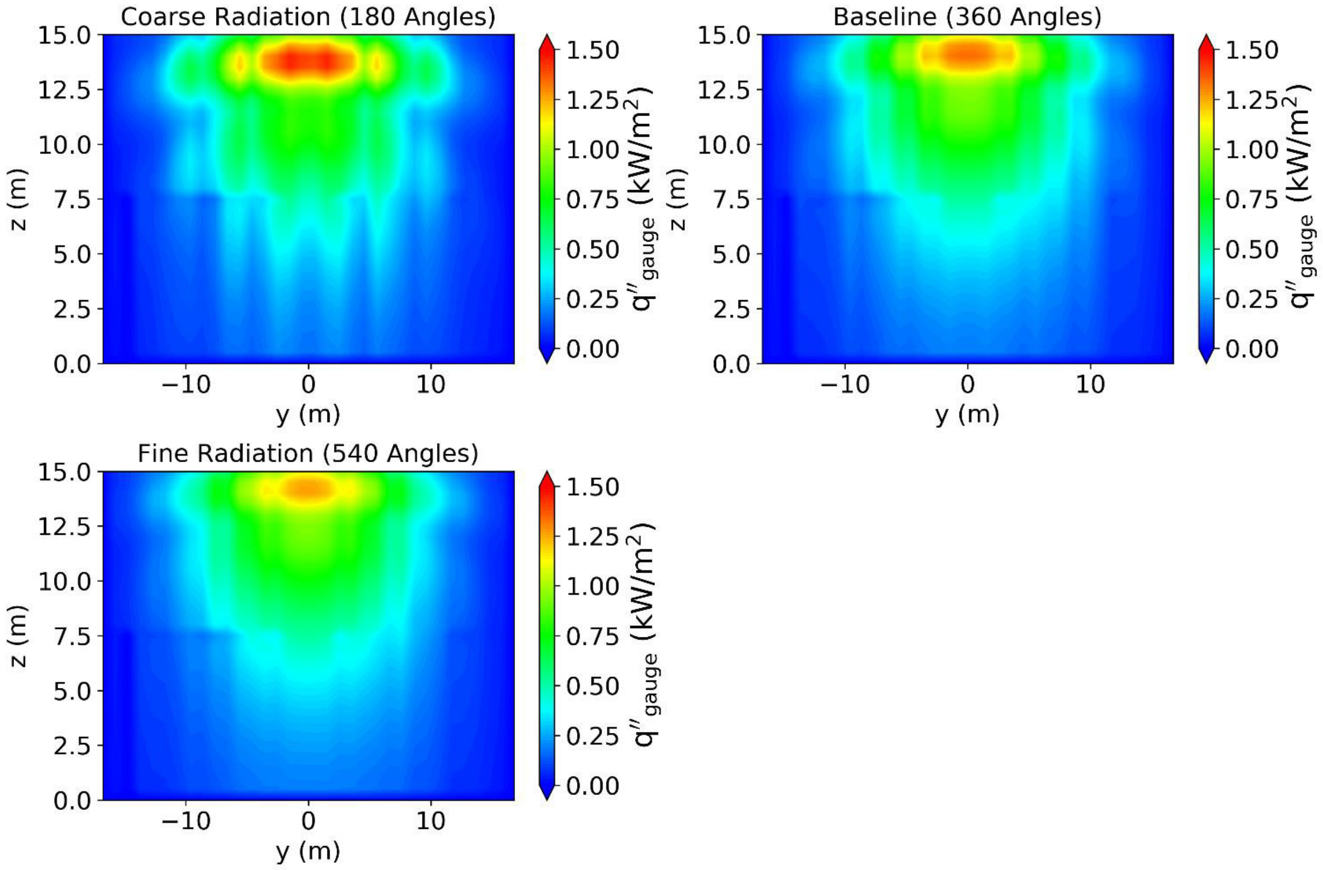


Figure A-29. Sensitivity assessment of radiation angles on quasi steady state thermal exposure on adjacent tank.

Figure A-30 compares the quasi steady state thermal exposure on the adjacent tank using the baseline configuration with no wind initialization (steady burning from t = 0 seconds) with that of a simulation with the wind field initialized for 60 seconds prior to ignition. These results indicate that the quasi steady state thermal exposure is independent of the wind initialization, with the difference in peak exposure 1.5% and a RMSE of 0.006 kW/m^2.

One of the key parameters in the radiation transport equation is the absorption coefficient in the gas phase. FDS computes the absorption coefficient using an external software, RADCAL [37]. The absorption coefficient in RADCAL is calculated based on the species concentrations, gas temperature, and radiative path length. The path length is used to compute the path mean absorption coefficient. Essentially, this term represents the difference in radiant intensity emitted by a uniform gas layer of thickness equal to the radiative path length and that of a black body at the effective temperature of flame radiation. The default path length used in FDS is 0.1 m

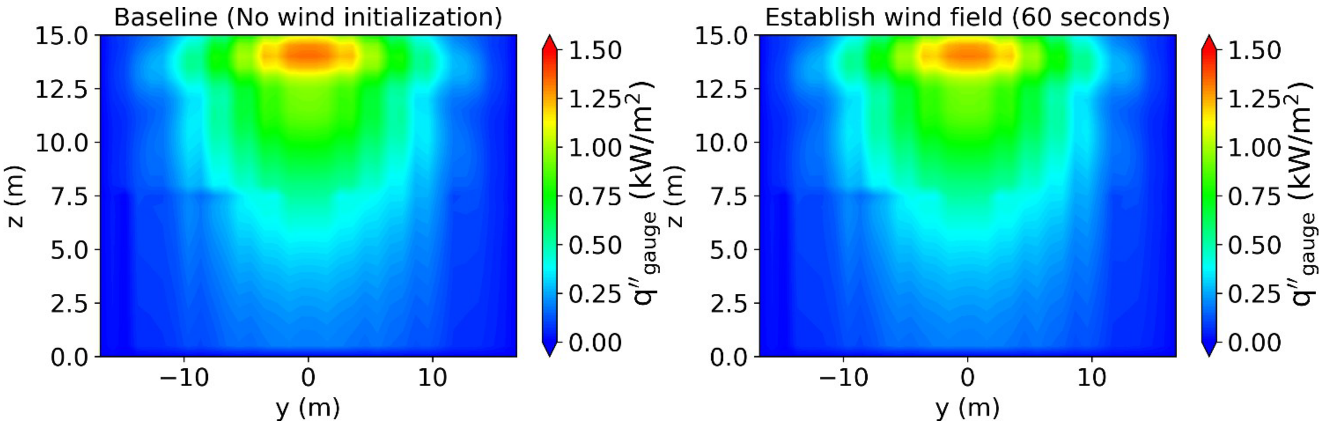


Figure A-30. Sensitivity assessment of wind initialization on quasi steady state thermal exposure on adjacent tank.

which is used in the FDS Validation guide. However, this path length may be larger in the ITC fire scenario due to the high separation distance between tanks. A sensitivity case was simulated with the path length increased by a factor of 10x (path length of 1.0 m) to better understand the impact of the default path length on the ITC fire simulations.

Error! Reference source not found. compares the quasi steady state thermal exposure on the adjacent tank using the baseline configuration. The top row of the figure shows the direct comparison between the two numerical simulations. The peak exposure is approximately 2x higher in the increased path length simulation over the baseline case (2.75 kW/m^2 versus 1.34 kW/m^2). In the bottom row, the predicted thermal exposures from the larger radiative path length case were linearly scaled by a factor of 2. The bottom row shows the general profile is in agreement, with the difference in peak exposure after scaling 2.2% and the RMSE 0.086 kW/m^2. These results indicate that uncertainty in the radiative path length could result in the baseline model predictions under predicting the thermal exposure by a factor of 2. Unfortunately, there is not a strong experimental basis to use in selecting the radiative path length which makes it difficult to determine which is a more accurate representation of the fire scenario. For this analysis, it was decided to proceed with the default 0.1 m radiative path length based on the quantified uncertainty in the FDS validation guide. However, the uncertainty in radiative path length is further discussed in the context of overall uncertainty in the discussion section.

OVERVIEW OF ADDITIONAL SCENARIOS

Additional permutations of the baseline configuration were simulated to examine the sensitivity of the thermal exposure predictions to different modeling inputs. These studies considered the impact of wind speed, changes in the pressure release vents, increases in fuel evaporation rate, and uncertainty in combustion radiative fraction. An additional scenario was simulated with the addition of a pool fire at the base of the model. The simulation matrix summarizing the permutations is shown in

.

Results from simulations with five different wind speeds are compared in Table A-3 and Figure A-31. In general, the maximum thermal exposure was not highly sensitive to the wind speed in the model, varying by approximately ±5% from the baseline case. However, the spatial variation in thermal exposure varied more significantly, as is seen in the increase in the root mean square difference (RMSD) from the baseline configuration. This difference was particularly prevalent in the 6.7 m/s (15.0 mph) wind configuration. Figure A- 31 shows that the increase in RMSD corresponds to an increase in the thermal exposure at the edges and bottom of the tank. In addition, the peak region is shifted down approximately 1.0 m (3.3 ft).

Results from simulations with four different vent configurations are compared in Table A-4 and Figure A-32. This assessment was done by varying either the vent area or total number of vents. The maximum thermal exposure

Table A-2. Model input sensitivity study simulation matrix.

Scenario	Wind Speed [m/s (mph)]	Heat Release Rate [MW]	Radiative Fraction, χ_r	Number of Vents	Vent Width [cm (in)]	Vent Height [cm (in)]
Baseline	2.2 (5.0)	63.2	0.43	26	50 (19.7)	50 (19.7)
Fuel source, 25% more volatile,	2.2 (5.0)	79.0	0.43	26	50 (19.7)	50 (19.7)
Fuel source, 50% more volatile	2.2 (5.0)	94.8	0.43	26	50 (19.7)	50 (19.7)
Fuel source, 10% higher χ_r	2.2 (5.0)	63.2	0.53	26	50 (19.7)	50 (19.7)
Fuel source, additional pool fire	2.2 (5.0)	136.0	0.43	26	50 (19.7)	50 (19.7)
Vents, fewer	2.2 (5.0)	63.2	0.43	19	50 (19.7)	50 (19.7)
Vents, larger	2.2 (5.0)	63.2	0.43	26	75 (19.7)	50 (19.7)
Vents, smaller	2.2 (5.0)	63.2	0.43	26	75 (19.7)	25 (19.7)
Wind, None	0.0 (0.0)	63.2	0.43	26	50 (19.7)	50 (19.7)
Wind, 2.7 mph	1.2 (2.7)	63.2	0.43	26	50 (19.7)	50 (19.7)
Wind, 10.0 mph	4.5 (10)	63.2	0.43	26	50 (19.7)	50 (19.7)
Wind, 15.0 mph	6.7 (15)	63.2	0.43	26	50 (19.7)	50 (19.7)

Table A-3. Statistical comparison of wind sensitivity.

Scenario	$\bar{q}''_{gauge,max}$ (kW/m^2)	$RMSD\ (kW/m^2)$
Wind, 0.0 m/s (0 mph)	1.25	0.084
Wind, 1.2 m/s (2.7 mph)	1.36	0.028
Wind, 2.2 m/s (5.0 mph)	1.34	-
Wind, 4.5 m/s (10.0 mph)	1.22	0.080
Wind, 6.7 m/s (15.0 mph)	1.31	0.199

increased in both the smaller vents and fewer vents scenarios, and decreased with the larger vents when compared to the baseline configuration. The largest change was observed in the smaller vent configuration where the peak thermal exposure increased by close 60%. The RMSD was significantly higher for the smaller and fewer vents scenarios than the larger vent scenario. Figure A-32 shows that the increase in RMSD corresponded primarily to an increase in size of the peak exposure region, rather than increases at the edges and bottom of the tank as seen in the 6.7 m/s (15.0 mph) wind configuration. The height of the peak exposure was not impacted by changing the vent configuration.

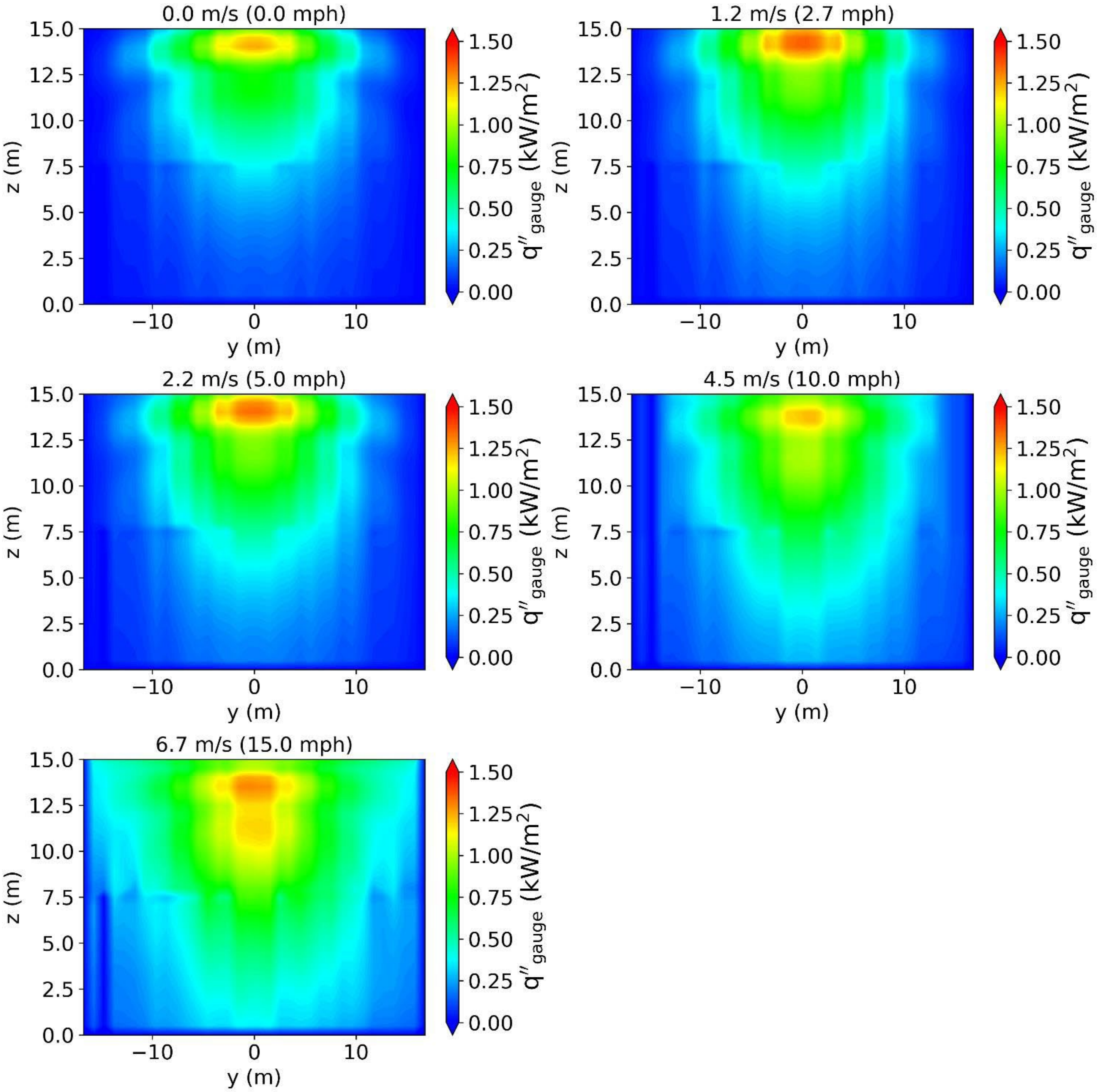


Figure A-31. Sensitivity assessment of wind speed on quasi steady state thermal exposure on adjacent tank.

Table A-4. Statistical comparison of vent sensitivity.

Scenario	$\bar{q}''_{gauge,max}$ (kW/m^2)	$RMSD$ (kW/m^2)
Baseline (26 vents – 0.50 m wide x 0.50 m tall)	1.34	-
Vents, fewer (19 vents – 0.50 m wide x 0.50 m tall)	1.63	0.110
Vents, larger (26 vents – 0.75 m wide x 0.50 m tall)	1.26	0.034
Vents, smaller (26 vents – 0.75 m wide x 0.25 m tall)	2.14	0.253

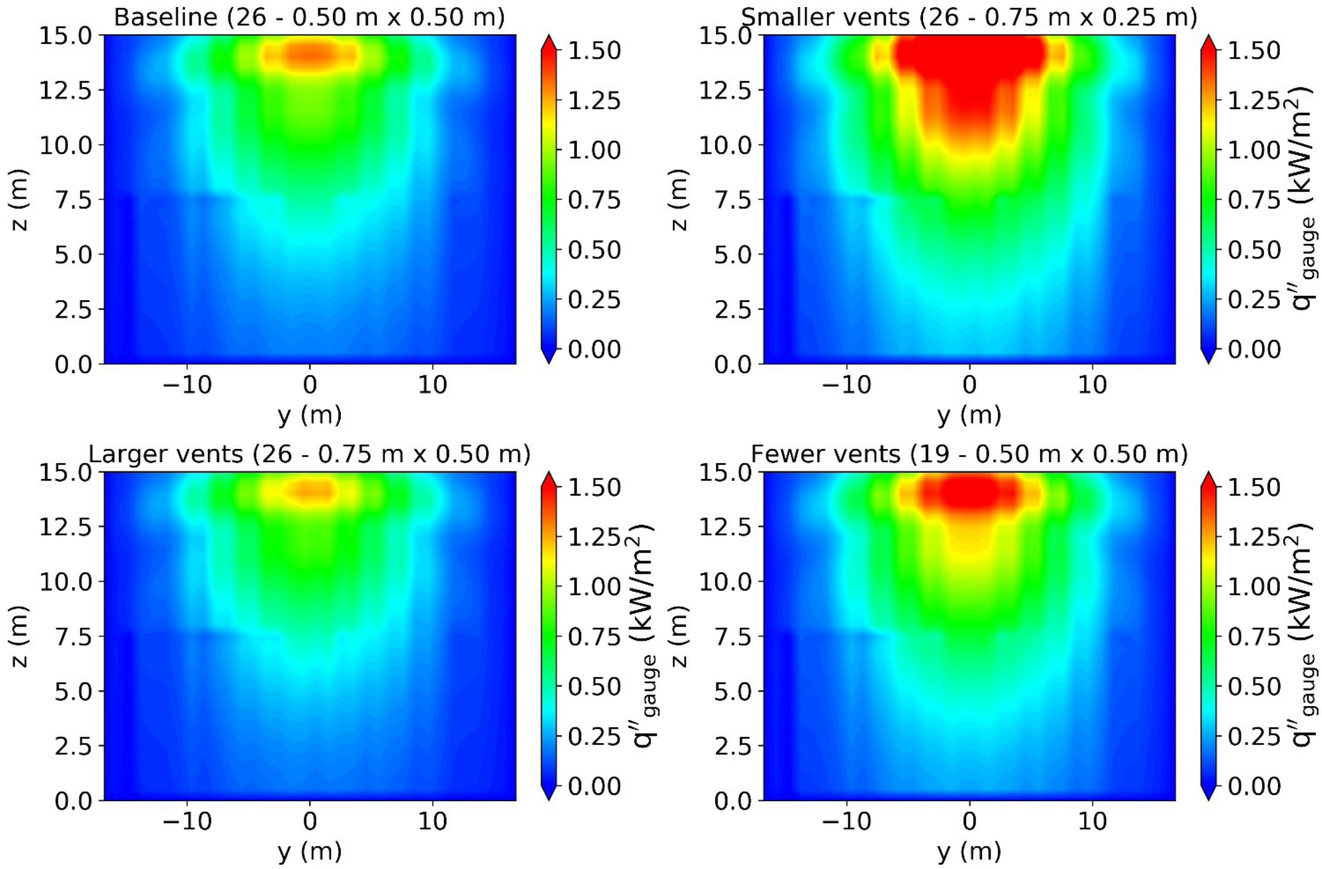


Figure A-32. Sensitivity assessment of vent configuration on quasi steady state thermal exposure on adjacent tank.

Four additional models were simulated to examine the impact of the fuel configuration on the predicted thermal exposures. In two scenarios, the overall heat release rate of the tank was increased by 25% and 50%, respectively. In another scenario the gas phase radiative fraction was increased by 10%. A large pool fire was added in the fourth scenario. The size and position of the pool fire was estimated based on aerial imagery from the ITC fire. The flames from the pool were observed to reach beyond the top of the tank (estimated at 15.0 m), and the base of the pool covered approximately one half of the separation distance between tanks (5.5 m). The heat release rate of the pool was estimated to be 72.9 MW using these observations by inverting Heskestad's flame height correlation, see Eq. 7 for reference. The center of the pool was placed at the corner of the projected square which inscribes the circle of the bottom of the tank, as shown in Figure A-33. The pool was specified as a square burner with a side length of 5 m so that the vent would directly align with the computational grid. The side length was selected based on an equal area diameter of 5.6 m. The mesh in the pool fire simulations extended the 25 cm grid to the bottom of the computational domain, and 5 m beyond the pool.

Results from the fuel configuration simulations are compared with the baseline thermal exposures in **Error! Reference source not found.**, Figure A-34, and Figure A-35. The maximum thermal exposure increased in each of the fuel configuration simulations relative to the baseline configuration. The 25% and 50% increase in heat release rate resulted in the peak exposure increasing by 22%, and 44%, respectively. The 10% increase in radiative fraction resulted in a 19% increase in the thermal exposure. However, the most significant impact was the addition of the pool fire, which increased the peak thermal exposure by 304%. Increasing the heat release rate and the radiative fraction increased the peak exposure area, but did not significantly increase the thermal exposure near the edges or bottom of the tank. In addition, the peak exposure location was not impacted by changing the heat release rate or radiative fraction. The addition of the pool fire significantly changed the profile of the thermal exposure. The heating on the adjacent tank was asymmetric, with the side closer to the pool experiencing heat fluxes 2-4x higher than the further side. In addition, the peak location occurred approximately 2.5 m above the ground, rather than 1.0 m below the rim of the tank.

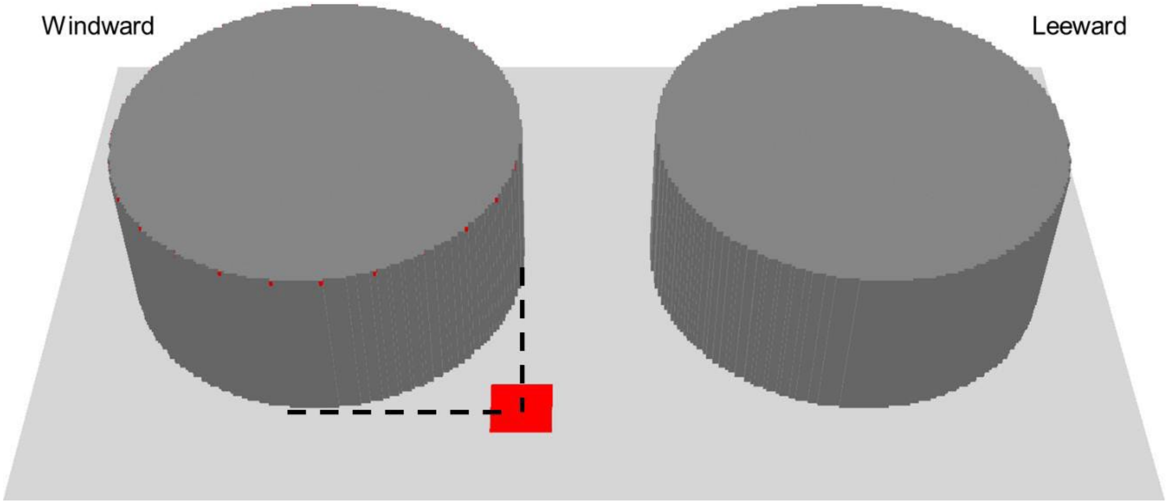


Figure A-33. Location of pool fire.

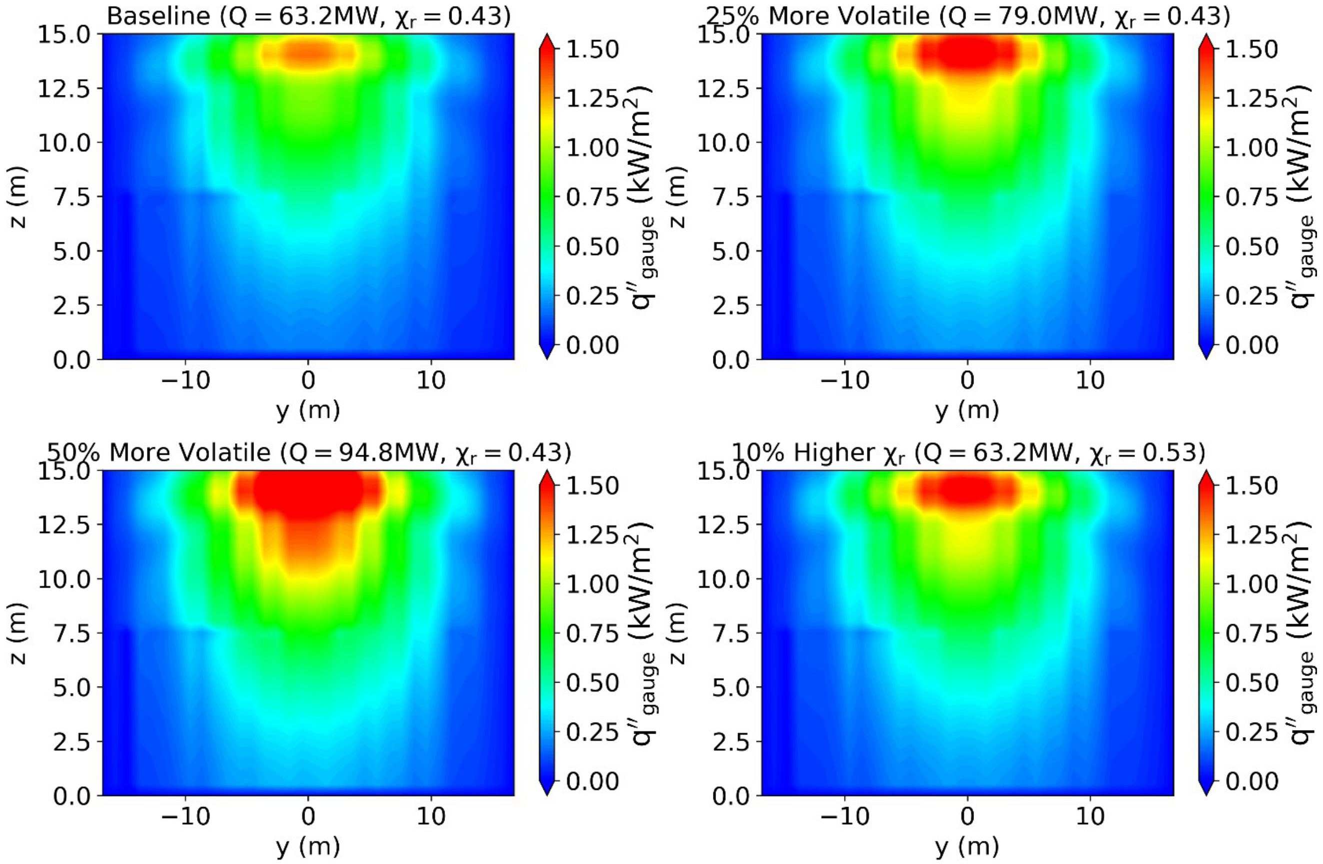


Figure A-34. Sensitivity assessment of fuel configuration on quasi steady state thermal exposure on adjacent tank.

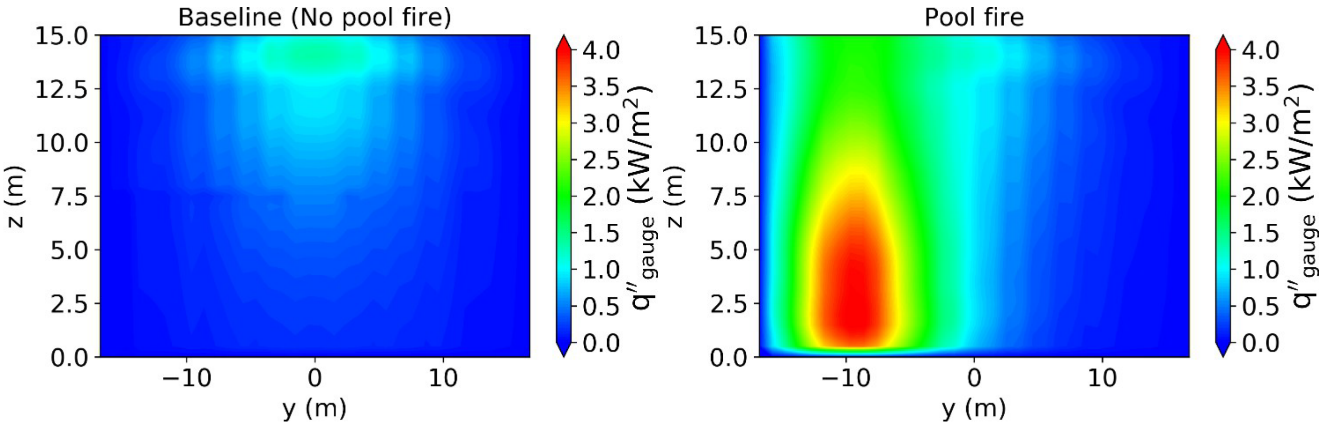
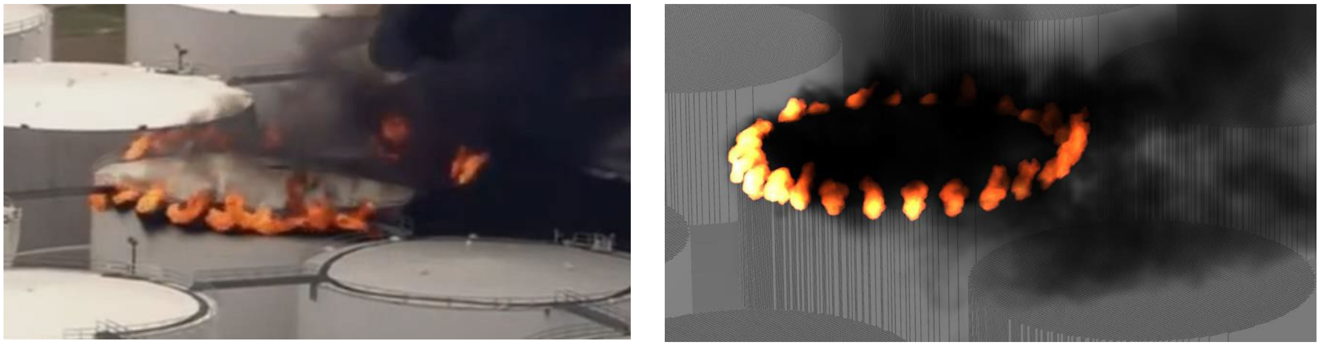


Figure A-35. Comparison of heat flux on adjacent tank with and without the addition of a pool fire.

A-4.4. DISCUSSION

Fire and smoke visualization of the baseline FDS simulation is compared with aerial imagery obtained during the ITC fire in Figure A-36. Qualitatively, the flame length and soot density agree well.



(a) Aerial imagery of ITC fire

(b) Fire and smoke visualization of CFD predictions

Figure A-36. Fire and smoke from aerial imagery compared with model predictions.

The heat flux versus distance from the baseline CFD model along the centerline is shown in Figure A-37. Figure A-37 shows that after the first 4 m of separation distance, the heat flux on the adjacent tank does not vary significantly with height.

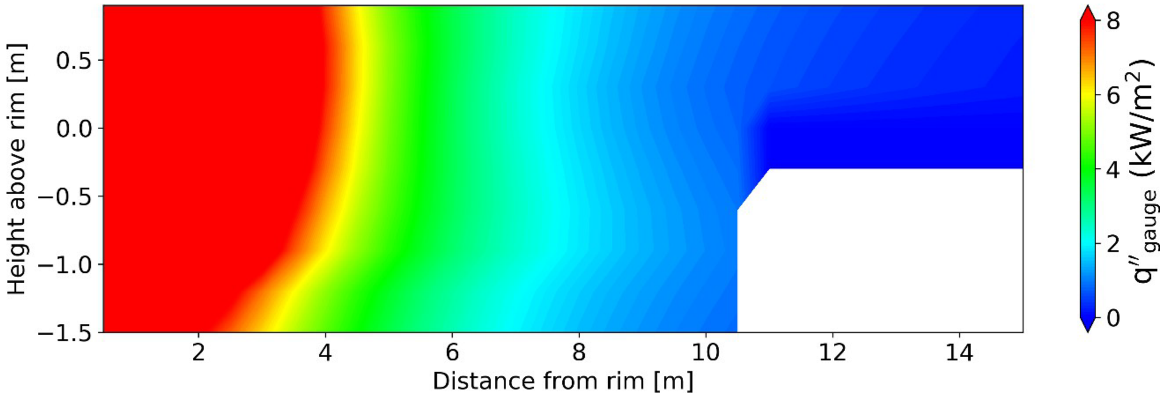


Figure A-37. Heat flux versus distance from rim from baseline CFD model.

The CFD thermal exposure predictions are compared with the hand calculation approaches in Figure A-38. Note that the tilted point source model was calculated using a radiative fraction of 0.10, based on the tank diameter correlation in Eq. 15. Note that the curve corresponding to the FDS maximum was calculated in post-processing by scaling the centerline measurements by the maximum observed off-center on the windward side of the tank. The results indicate that both hand calculation methods underpredict the thermal exposure to the adjacent tank compared with the detailed CFD model.

Recall that a large source of uncertainty in the tilted point source model is the unknown value of the radiative fraction to use. Radiative fraction in the point source model is an effective property which is a function of both the reaction and the geometry. However, radiative fraction in the CFD model is purely a property of the reaction. If we consider the entire computational domain as a control volume, an effective radiative fraction which accounts for the impact of the geometry in addition to that of the reaction can be calculated from the CFD predictions by comparing the ratio of energy leaving the control volume due to radiation to the heat released by the fire. The effective radiative fraction calculated from the baseline FDS simulation and the pathlength sensitivity simulation are shown in Figure A-39. The effective radiative fractions were found to be 0.06, and 0.08, respectively, which generally agree with the values recommended by Beyler.

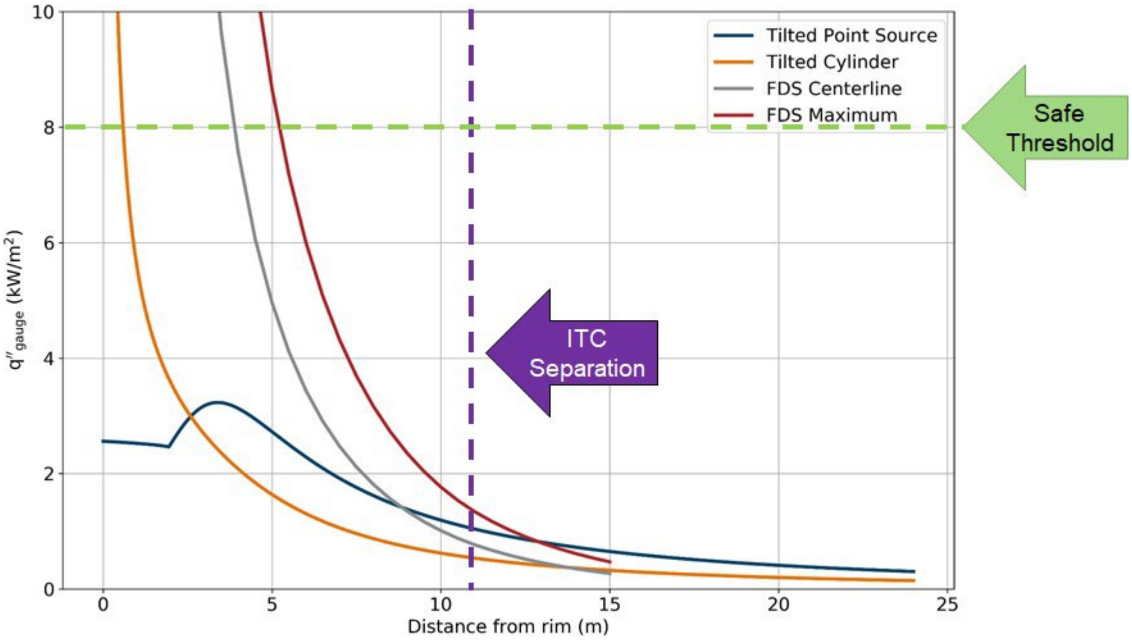


Figure A-38. Comparison of thermal exposure predictions using each approach.

The thermal exposure predictions after accounting for the model uncertainty for each case are summarized in Table A-5. Accounting for the uncertainty in FDS, the true thermal exposures could be a factor of 2x higher than those predicted by the model. This agrees with the variation observed in the path length sensitivity model. After accounting for the uncertainty in the modeling predictions, the model predicted thermal exposures in all scenarios without the pool fire are still below the industry accepted critical heat flux required to ignite an adjacent tank of 8 kW/m^2. However, after accounting for the uncertainties, there is a 15% chance the thermal exposure from the pool fire scenario could exceed the critical heat flux threshold. However, this does not account for the model input uncertainty in estimating the size and location of the pool fire. The pool fire in this analysis was 72.8 MW based on the observed flame heights; however, if the pool fire were actually larger, the chance to ignite the adjacent tank would increase.

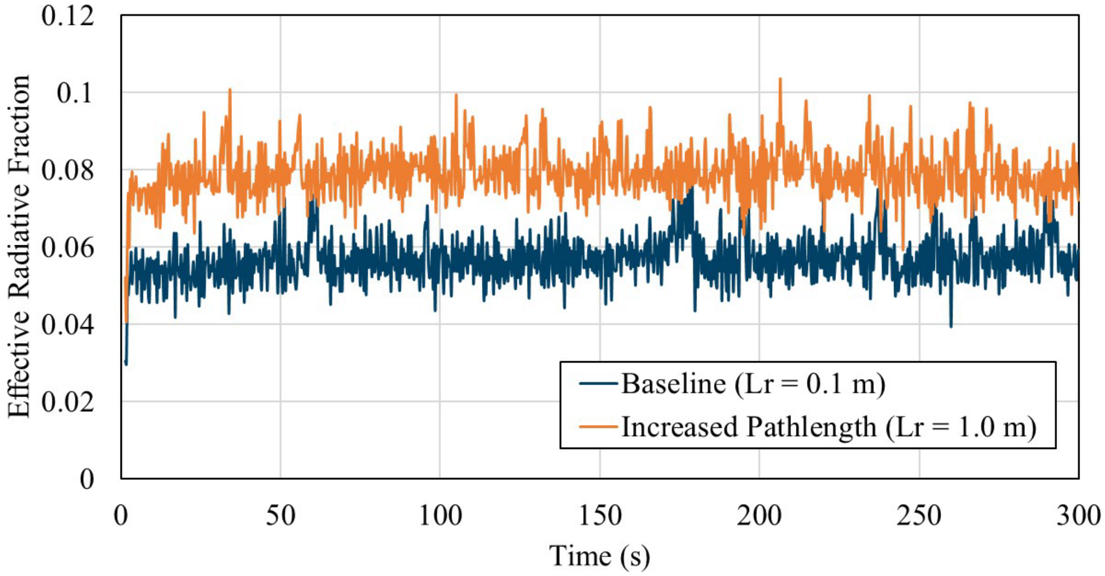


Figure A-39. Effective radiative fraction calculated from the baseline and pathlength sensitivity FDS simulations.

Table A-5. Statistical assessment of CFD predictions after correcting for model bias and uncertainty.

Scenario	$\bar{q}''_{gauge,max}\ (kW/m^2)$				
	Raw	50.0th Percentile	84.1th Percentile	97.5th Percentile	99.9th Percentile
Baseline	1.34	1.52	1.88	2.23	2.58
Fuel source, 25% more volatile,	1.64	1.86	2.39	2.92	3.45
Fuel source, 50% more volatile	1.93	2.19	2.92	3.66	4.39
Fuel source, 10% higher χ_r	1.60	1.82	2.32	2.82	3.33
Fuel source, additional pool fire	4.07	4.63	7.88	11.1	14.4
Vents, fewer	1.63	1.85	2.37	2.90	3.42
Vents, larger	1.26	1.43	1.74	2.06	2.37
Vents, smaller	2.14	2.43	3.33	4.23	5.1
Wind, None	1.25	1.42	1.73	2.03	2.34
Wind, 2.7 mph	1.36	1.55	1.91	2.27	2.64
Wind, 10.0 mph	1.22	1.39	1.68	1.97	2.26
Wind, 15.0 mph	1.31	1.49	1.83	2.16	2.50

A-5.0 Fire Modeling Conclusions

The results of the hand calculations and detailed fire modeling indicate that it is highly unlikely that the fire in Tank 80-8 would have resulted in ignition of fuels in the adjacent tanks without the contribution of an additional significant heat source, such as a large liquid pool fire on the ground. Existing prescriptive codes such as *NFPA 30: Flammable and Combustible Liquids Code* [8], *FM Loss Prevention Data Sheet (LPDS) 7-88: Ignitable Liquid Storage Tanks* [9], and *API Pub 2021: Management of Atmospheric Storage Tank Fires* [10] are based on industry experience and the contribution from a single fire source (in example, either a liquid pool or an adjacent tank).

The results of this study indicate that the coupled impact of a tank fire and a liquid pool fire may need to be considered in evaluating the minimum safe separation distance, particularly in older installations that predate the availability of safety features or equipment that aid in mitigating such conditions. Although a relatively limited pool fire was examined in this analysis, the combined impact of the pool and vent fires significantly raised the radiant exposure to adjoining tanks. If the pool fire expanded, as was the case with the ITC fire, igniting the contents of adjacent tanks from radiant heat exposure would be more likely.

In addition, the computational modeling showed that the fires exiting vertical pressure release vents on the side of the tank behaved significantly differently than a standard liquid tank fire, where the impact of wind on the thermal exposure was significantly less than has been documented in similar studies for other tank farms. In this study, the size and number of pressure release vents had a more significant impact on the predicted thermal exposure than the wind speed. Because this configuration is a trend within the tank storage industry, additional study appears to be necessary based on clearly different burning and radiant exposure mechanisms that have traditionally been incorporated into the above noted standards. The configuration also highlights the need for prescriptive codes to consider alternative fire configurations when recommending minimum safe distances.

These conclusions are incorporated into Section 6.0 of the body of this report.

A-6.0 Appendix References

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Perspectives on Containment Wall Failure at ITC Deer Park, Texas

Fire at First & Second 80's Tank Farm at Intercontinental Terminals Company
Event of March 17, 2019 at Deer Park, Texas

Tank Farm at the time of Containment Wall Failure, ITC First and Second 80's Tank Farm

Issued Date
April 24, 2023

Prepared for
U.S. Chemical Safety and Hazard Investigation Board 1750 Pennsylvania Avenue, NW Suite 910
Washington, DC 20006

Prepared by Atlas Engineering, Inc. 551A Pylon Drive Raleigh, NC 27606 Firm License #: C-1349

ENGINEERING, INC.

April 24, 2023

U.S. Chemical Safety and Hazards Board 1750
Pennsylvania Avenue, NW Suite 910
Washington, DC 20006

Attention: **Crystal Thomas**
Chemical Incident Investigator
U.S. Chemical Safety and Hazard Investigation Board

Subject: **Perspectives on Containment Wall Failure at ITC Deer Park, Texas**
Fire at First & Second 80's Tank Farm at Intercontinental
Terminals Company
Event of March 17, 2019 at Deer Park, Texas

Ms. Crystal Thomas,

Atlas Engineering is pleased to provide this report on the fire and subsequent containment wall failure that occurred at the first and second 80's tank farm at Intercontinental Terminals Company, Deer Park Texas on March 17, 2019. The following is our perspective on the likely mode of failure for the containment wall and the potential lessons learned from this event.

Atlas Engineering visited the site on July 7, 2021, and reviewed the documentation available from the excavation of the containment wall footing on June 9, 2022. Our work for this has been performed in accordance with CSB's request on May 27, 2021.

Atlas Engineering appreciates this opportunity to be of service. Please call on us with any questions at 919-420-7676.

Sincerely,

Atlas Engineering, Inc., by

Matt Poisel

NORTH CAROLINA PROFESSIONAL ENGINEER SEAL 041451 MATTHEW J. POISEL
4/24/2023

Gec Matt Poisel, PE
Gec Principal Engineer

Background

A fire occurred at a tank farm on Intercontinental Terminals Company (ITC) property on March 17, 2019. The fire occurred in a section of the facility known as the “first and second 80’s” tank farm, hereafter referred to as the tank farm. This tank farm is located at the south-west corner of the intersection of Tidal Road and Independence Parkway in Deer Park, Texas (figure 1). The fire originated at tank 80-8 and proceeded to spread throughout the tank farm over the next serval days despite firefighting efforts. On March 22, 2019, a section of the north secondary containment wall failed, permitting product, water, and firefighting foam to flow into a drainage ditch along Tidal Road and into the Tucker Bayou waterway north of the site. The United States Chemical Safety and Hazard Investigation Board (CSB) has investigated this incident and as part of the investigation has requested that Atlas Engineering provide our opinion on the potential reasons for the containment wall failure and lessons-learned from this incident.

Figure 1: ITC Deer Park, Texas Facility with “First and Second 80’s” Tank Farm Indicated[1] imagery date: March 20, 2019

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[1] Google Earth Pro, historical aerial photo, imagery date: March 20, 2019

ITC Tank Farm Construction

The tank farm consisted of fifteen 80,000-barrel tanks arranged on a grid with five tanks in the east-west direction and three tanks in the north-south direction (figure 2). A concrete containment wall surrounded the site on four sides. The ground surface inside the tank farm was indicated by ITC as natural grade soil covered with a minimum of six inches of stabilized materials consisting of crushed limestone, crushed concrete, cement stabilized sand, or similar materials.[2] The site was sloped gradually from north to south, with a stormwater drainage system collecting water at the south edge of the tank farm and directing it through pipes and control structures to the drainage ditch near the north-west corner of the site.[3]

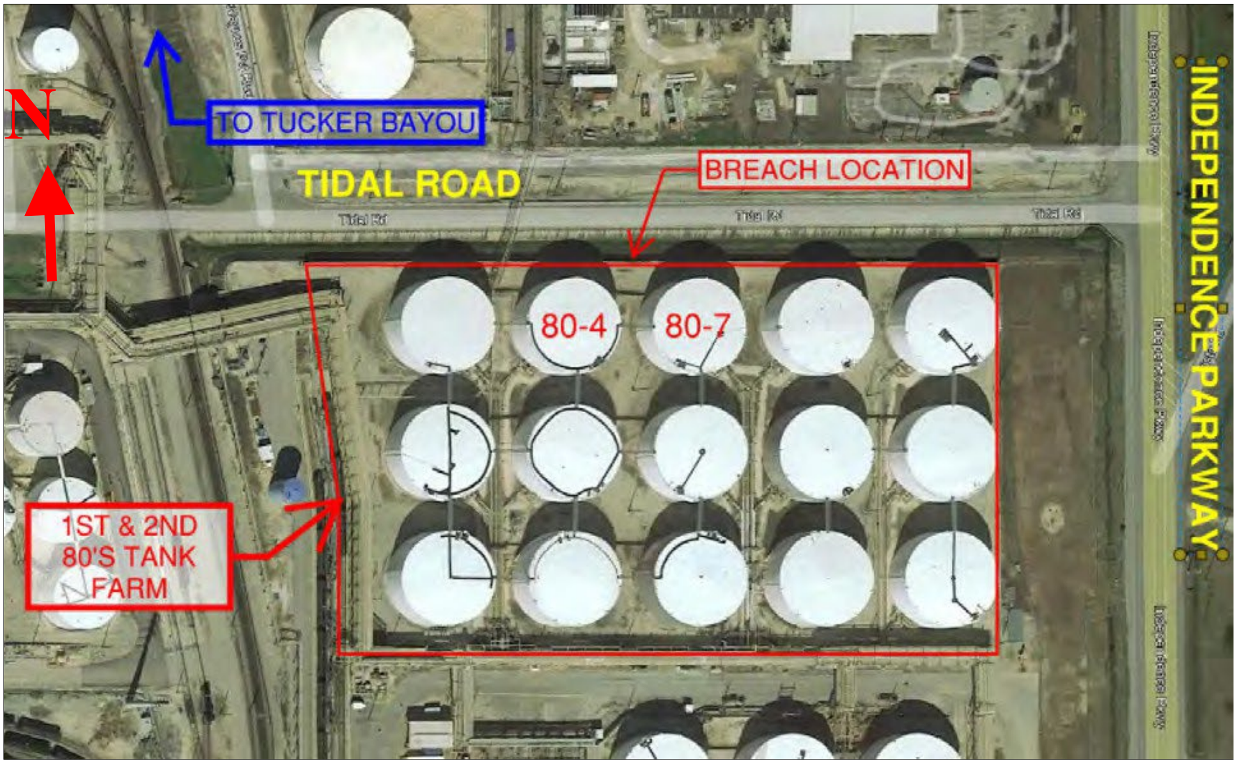

Figure 2: First and Second 80's Tank Farm, prior to incident; imagery date: February 23, 2019[4]

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[2] Letter, "ITC Secondary Containment Systems" from Joe Thayer, dated February 22, 2006

[3] File, "ITC Response to Drainage Inquiry" & ITC drawing SW 003, rev A, "Plot Plans - Storm Drain System", dated 6/22/12

[4] Google Earth Pro, historical aerial photo, imagery date: February 23, 2019

The roads currently named as Tidal Road and Independence Parkway existed at the site prior to the construction of the tank farm in a general location that is consistent with the existing roads.[5] There did not appear to be a concrete lining to the drainage ditch on the south side of Tidal Road in this aerial photo (photo 1). The tank farm was not constructed at this point in time.

Photo 1: Site of tank farm prior to construction, aerial imagery date: 1953, source: Google Earth Pro

Limited documentation was available on the construction on the tank farm. No design or as-built drawings were made available for review. Permits indicated that construction started in 1976 or 1977.[6] Historical aerial photos obtained from Google Earth Pro show the tank farm containment wall as being completed by 1978.[7] From the 1978 aerial photo (photo 2, next page), the drainage ditch north of the tank farm did not appear to be lined with concrete at the time of construction of the tank farm. The first historical aerial photo available that appears to indicate a concrete lining of the drainage ditch south of Tidal Road and north of the tank farm was from 1989 (photo 3, next page).[8]

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[5] Google Earth Pro, historical aerial photo, imagery date: 1953, indicated source: "Texas General Land Office"
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Photo 2: Aerial photo of first & second 80's tank farm, 1978

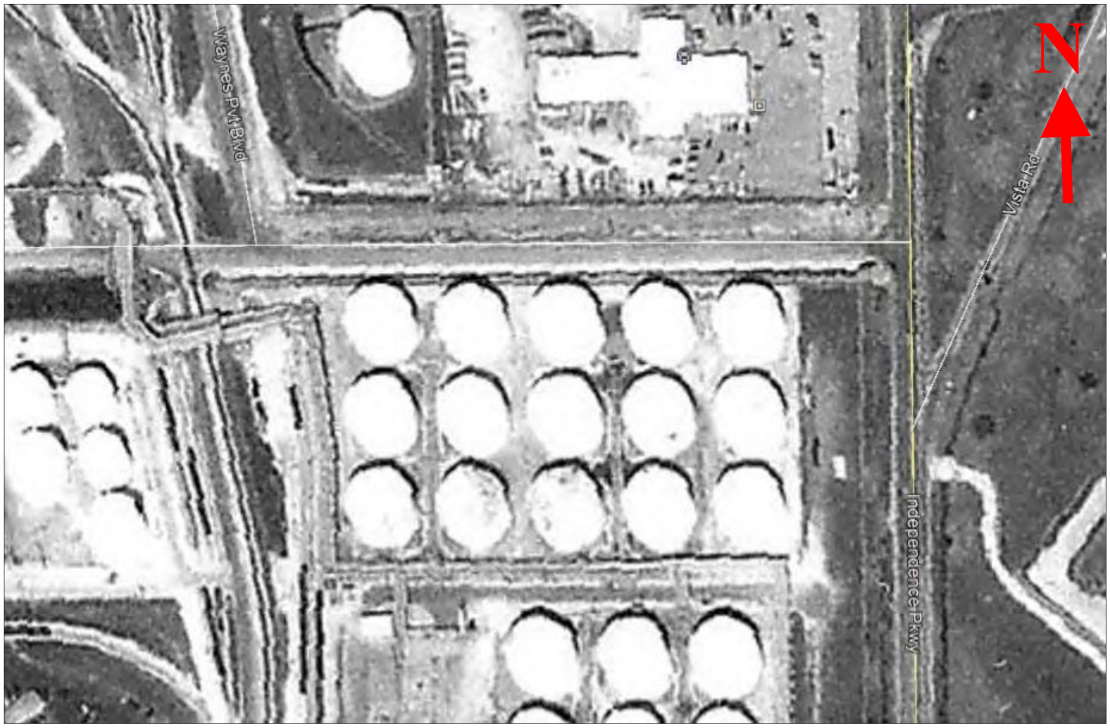

Photo 3: Aerial photo of first & second 80's tank farm, 1989

Fire Event, Response, and Containment Failure

The following is a partial summary of the fire event and response, including the events leading up to the breach of the north containment wall and the response after the breach occurred. This summary is based on a timeline compiled by the Chemical Safety Board[9] and the Summary of Current Actions produced by the Incident Command Planning Group of the response team.[10]

At approximately 10:00am on March 17, 2019, a fire broke out at the first and second 80's tank farm at ITC Deer Park Terminal. The ITC Emergency Response Team and the Channel Industries Mutual Aid organization (CIMA) fought the fire between March 17 and March 22 as the fire grew and spread to the majority of the tanks inside the tank farm. Firefighting operations consisted of the application of firefighting foam mixed with water in attempts to suppress the fire as well as the application of water to cool surrounding tanks from exposure to the fire in an effort to prevent the fire from spreading. These efforts involved the application of water on the order of magnitude of 20,000 gallons of water per minute during firefighting operations inside the secondary containment area[11]. As the fire spread and tanks were damaged, the contents of the tanks flowed into the secondary containment area as well.

Firefighting efforts involved attempting to maintain a continuous blanket of firefighting foam over the exposed product in damaged tanks and the secondary containment area for the duration of the event until thermal imaging indicated that the contents of the site had cooled sufficiently to prevent re-ignition. As a result of these efforts, the area inside the secondary containment walls, as well as the surrounding area of the site, was exposed to a continuous application of water, foam, and spilled hydrocarbon liquid products for six days prior to the breach. The level of liquids inside the secondary containment walls varied over time as water was applied, individual tanks failed, and as drains and pumps were utilized in an attempt to prevent the liquids from overflowing the secondary containment area.

On March 22, the fire had been successfully suppressed and the firefighters were periodically re-applying additional firefighting foam to maintain a continuous blanket of foam across the site. UAS overflights were being conducted periodically to observe the status of the tank farm. Operations planned for that day included removal of product from vessel 80-7 by utilizing a concrete pump truck to reach damaged vessels from outside the containment wall. Drains and pumps throughout the site were also being used to lower the liquid level inside the containment area. But at approximately 12:00pm on March 22, a section of the containment wall on the north side of the tank farm, between tanks 80-4 and 80-7, failed, allowing the liquid mixture inside the tank farm to flow into the drainage ditch between the tank farm and Tidal Road (photo 4).

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[9] CSB document "ITC timeline – FINAL (August 27, 2020)"

[10] ICS 201-2 Summary of Current Actions, prepared by Incident Command Planning Group, updated 03/23/2019 07:54 UTC

[11] Jensen Hughes report "Perspectives on Tank Farm Fire ITC Deer Park (Texas), March 2019" rev 1, dated September 22, 2020.

Photo 4: Containment wall failure (red arrow) during fire suppression efforts[12]

The response team had to retreat from immediately impacted areas. Flare-ups of fire in the drainage ditch and tank farm required re-application of firefighting foam. The team deployed additional booms in the waterways to contain product, and took measures to mitigate the leak from the tank farm. Initially, the incident response team utilized T-rail Jersey Barriers and sandbags inside the tank farm in an attempt to build a new containment structure to stop the breach and reestablish containment. This was augmented on March 23 by bringing in off-site soils to reinforce the immediate measures and construct a dike wall inside the breach (photo 5).

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[12] CSB investigation photo:

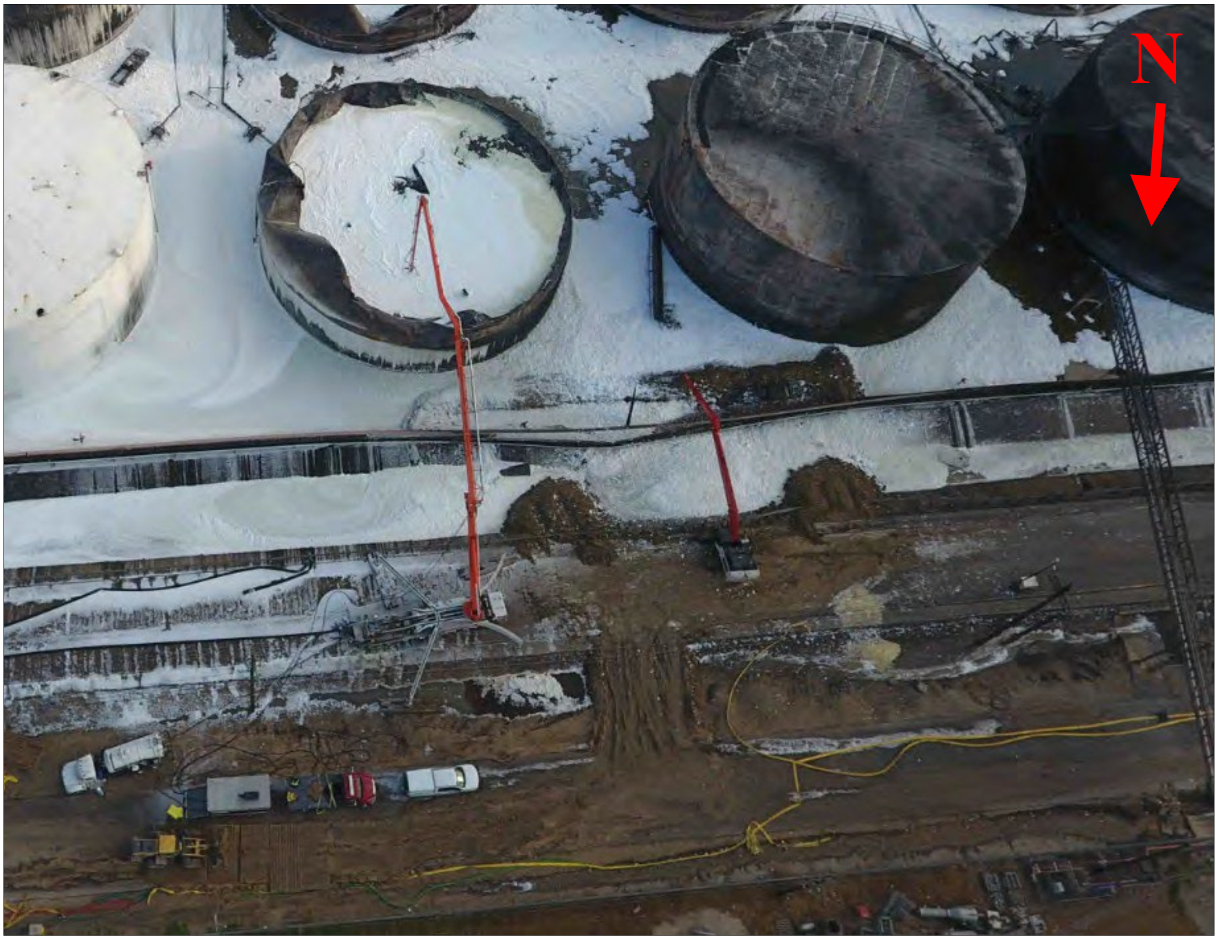

Photo 5: Responders constructing soil dike wall inside containment area to mitigate breach[13]

The Summary of Current Actions document made available to us stops at 07:00am on March 23. No additional documents from the incident management team were made available for review. Eventually, the incident response team was able to stabilize the site and begin remediation measures.

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[13] CSB investigation photo:

Observations from Videos and Photos Provided

UAS overflight video footage was made available to Atlas by the CSB to aid in determining the condition of the wall during the event. Aerial footage showed that a section of the wall had shifted laterally to the north, tearing the waterstop at multiple construction joints and permitting fluid to flow into the drainage ditch north of the tank farm (photo 6). The wall remained straight and continuous between construction joints. A section of the soil immediately south of the containment wall shifted laterally as well, opening a crack in the ground surface that permitted large volumes of fluid to wash down into the soil. A steel pipe that was supported on top of the containment wall was separated from the wall as it displaced, but appears to have remained intact and was suspended above the area of the breach. The two pipes on the exterior of the containment wall, one black and the other white, were displaced by the wall.

Large volumes of firefighting foam flowed out of the containment area during this event, with foam traveling underneath the containment wall at the area of the breach. No foundation was visible in the photo, indicating that the wall may have separated from the foundation slab as it shifted. Much of the drainage ditch is obscured by foam, but there are indications that the sloped slabs lining the ditch, adjacent to the containment wall, have displaced.

Photo 6: Closeup from aerial view of containment wall failure[14]

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[14] CSB investigation photo:

Photo 7 was taken after the bulk of the liquid had ceased to flow from the breach in the containment wall, but before emergency measures to build a temporary berm were taken. In this photo, a large erosion gulley has been formed at the location of the primary breach, between 80-4 and 80-7, with smaller erosion gullies formed at adjacent construction joints in the wall where the waterstop was compromised as the wall shifted. The crack in the soil is visible parallel to the containment wall that resulted from the lateral shift of the wall and soil immediately behind the wall. The firefighting water distribution pipe running parallel to the containment wall can be seen exposed where the soil eroded away. It is not possible to determine if the foundation was displaced from its original position from this photo. The remains of a wood light pole that has been burned can be seen standing in this area. The remaining section of the light pole is still vertical. The sloped slabs on the south side of the drainage ditch have been displaced, with many buckling in the middle and some displaced entirely by the flow of liquid into the ditch. Eroded soil can be seen in the drainage ditch.

Photo 7: Aerial photo of containment wall failure after water flow stopped and before temporary dike wall was constructed[15]

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[15] Photo extracted from UAS video, CSB investigation file:

A photo of the breach after the response team had placed soil inside the tank farm to build a temporary berm can be seen in photo 8. The containment wall can be seen to have shifted laterally, with a slight outward rotation in this photo. The wall sections remained intact between construction joints, however the lateral displacement of the wall had resulted in gaps and torn waterstop at several construction joints. The sloped slabs on the south face of the drainage ditch can be seen buckled upward.

Photo 8: View of containment wall failure, after temporary dike wall was constructed[16]

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[16] CSB investigation photo:

A close-up photo of the primary breach location can been seen in Photo 9. The soil had been eroded away from both sides of the containment wall at the breach. The wall had separated at a construction joint, and no dowels were visible spanning across the construction joint. The bottom of the wall was not visible in this photo, and it cannot be determined from this photo if the wall had a footing. The soil on the lower- right corner of the photo was soil placed after the breach to form the temporary dike wall. The temporary dike wall constructed by the responders inside the containment area can be seen in the upper left corner of the photo.

Photo 9: Close-up photo of containment wall breach provided by CSB[17]

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[17] CSB investigation photo:

Observations from Site Visit

Atlas Engineering was contacted by the CSB on May 27, 2021 regarding this incident. The CSB requested our assistance in determining the likely failure mode of the containment wall, and in finding the lessons learned from this event. Atlas Engineering visited the site on July 7, 2021 to view the existing condition of the site as well as make observations from the containment wall construction. Our observations consisted of a UAS flight over the site, photographs of structures, field measurements on exposed sections of the containment wall, and in taking samples of the site soil.

At the time of our site visit, remediation measures had been performed. These included draining the product and water from the site as well as removal of the existing tanks and above-grade piping. The top surface of the soil inside the containment area appeared to have been significantly disturbed by these initial remediation measures. The additional soil brought in to construct the containment remained in place. New T-rail Jersey barriers were in place, likely to prevent equipment involved in the remediation of the tank farm from entering the section of the breach. The elevated pipes that were located just outside the tank farm wall had additional temporary supports added where the original supports were disturbed in the breach. Erosion ditches at the area of the breach had been backfilled. Some sections of the damaged concrete slab that had lined the drainage ditch between the tank farm containment wall and Tidal Road had been removed, as well as sections of the damaged portion of the containment wall. The immediate area of the breach was thoroughly disturbed from the remediation and stabilization operations. However, sections adjacent to the breach along the containment wall appeared to remain minimally disturbed since the incident (Photo 10).

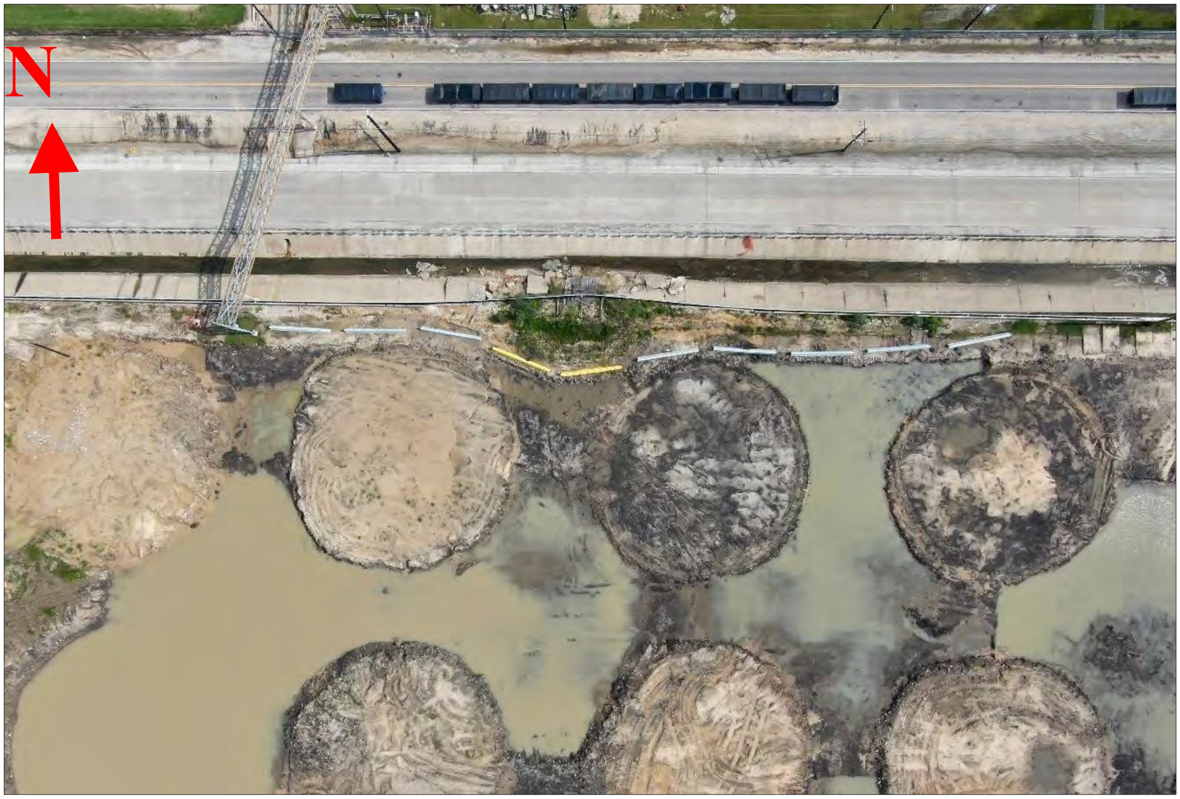

Photo 10: Aerial view of side during July 7, 2021 site visit

Measurements of the existing wall and drainage ditch were taken to construct a cross section sketch of the area (Figure 3). Measurements of reinforcement in the containment wall were made at locations where the containment wall had been broken by equipment during remediation efforts (Photo 11).

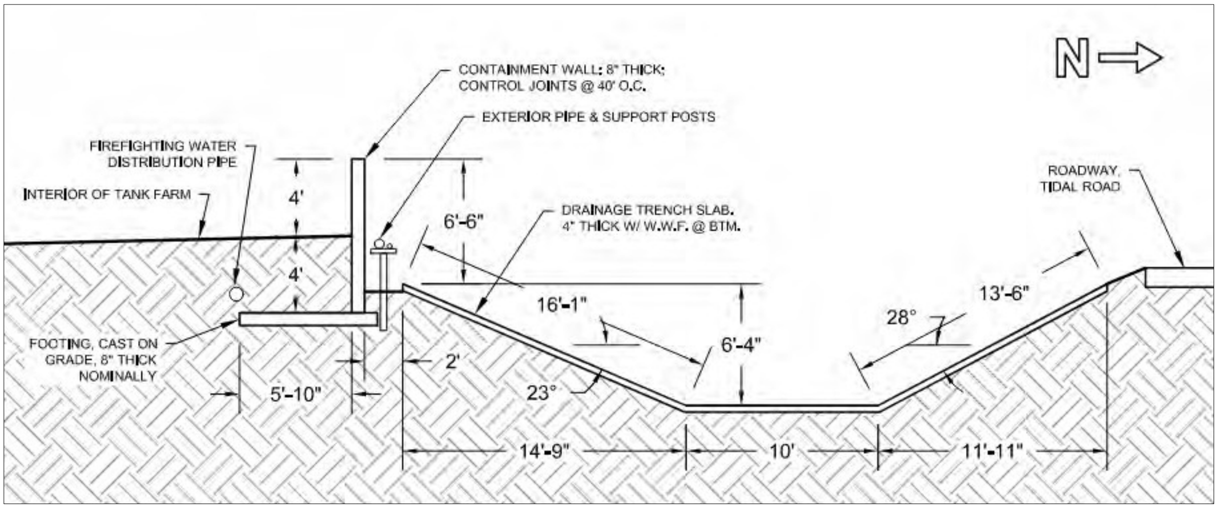

Figure 3: Cross section sketch of the containment wall

Photo 11: Exposed reinforcement at a section of the east containment wall where the wall was removed during remediation efforts

The containment wall was a cast-in-place concrete wall 8-inches thick and extending above the interior grade of the tank farm approximately 4 feet. The depth of the containment wall into the soil was not able to be determined at this visit. The wall had impressions from a panelized formwork system and through- wall break-off form ties, or snap-ties, spaced regularly in the horizontal and vertical direction, indicating it was constructed free-standing with a panelized formwork system on each face (photo 12). The wall was reinforced with two layers of deformed mild-steel reinforcing bars. The wall was cast in sections, with a construction joint every 40 feet. The joints were formed with a shear-key at the joint and a ribbed-wing centerbulb PVC waterstop incorporated into the construction joints to prevent liquids from leaking through the wall at the joints (photo 13 & 14).

Photo 12: Norh concrete retaining wall, outside face. Form tie marks on wall

Photo 13: Construction joint with cast-in concrete shear key and centerbulb waterstop

Photo 14: Torn waterstop and displaced wall. Upper section of wall that was dispaced has been partially demolished during remediation efforts.

The drainage ditch between the containment wall and Tidal Road was a concrete-lined structure with a flat bottom and sloped side walls (photos 15 & 16). The concrete slab was approximately 4-inches thick, with welded-wire-reinforcement observed at broken sections of the concrete, typically located near the bottom of the slab. The concrete slabs were cast in sections, with construction joints between the slabs (photo 17). The welded-wire reinforcement did not span across the construction joints. Holes through the slab were observed along the bottom edge of the sloped side-wall slabs, appearing to have the purpose of providing drainage of groundwater from behind the side slab into the drainage ditch. In the areas adjacent to the breach that appeared un-disturbed, sections of the sloped sidewall concrete slab had buckled upward in the middle of the slab.

Photo 15: Drainage Ditch, undamaged section at north-east corner, looking west

Photo 16: Damaged Section of Drainage Ditch, looking east

Photo 17: Displaced section of concrete slab that formed sloped sidewall of ditch

Atlas Engineering was not able to take destructive samples of the containment wall concrete during our fieldwork. We were not able to perform excavation of the wall base during this visit. Atlas requested that additional excavation be performed to identify the depth of the containment wall and if any footings existed for the containment wall. Atlas Engineering coordinated with ITC and the CSB to arrange for an excavation on the interior face of the containment wall down to expose the base of the wall at a later date.

During this visit, three isolated soil samples were taken with a hand trowel at a shallow depth from areas assumed to be soils existing at the time of the breach with locations shown in photo 18. Sample 1 was taken on the north side of the containment wall just west of the breach, at a location beneath a buckled slab of the drainage ditch (photo 19). Sample 2 was taken on the north side of the containment wall, further west of the breach, at a location beneath a buckled slab of the drainage ditch (photo 20). Sample 3 was taken on the north side of the containment wall, east of the breach, in an area that was not disturbed by the shifting wall of the breach (photo 21). No samples were taken inside the containment area since it appeared that the soil surface had be significantly disturbed during remediation efforts at the site and would therefore not be representative.

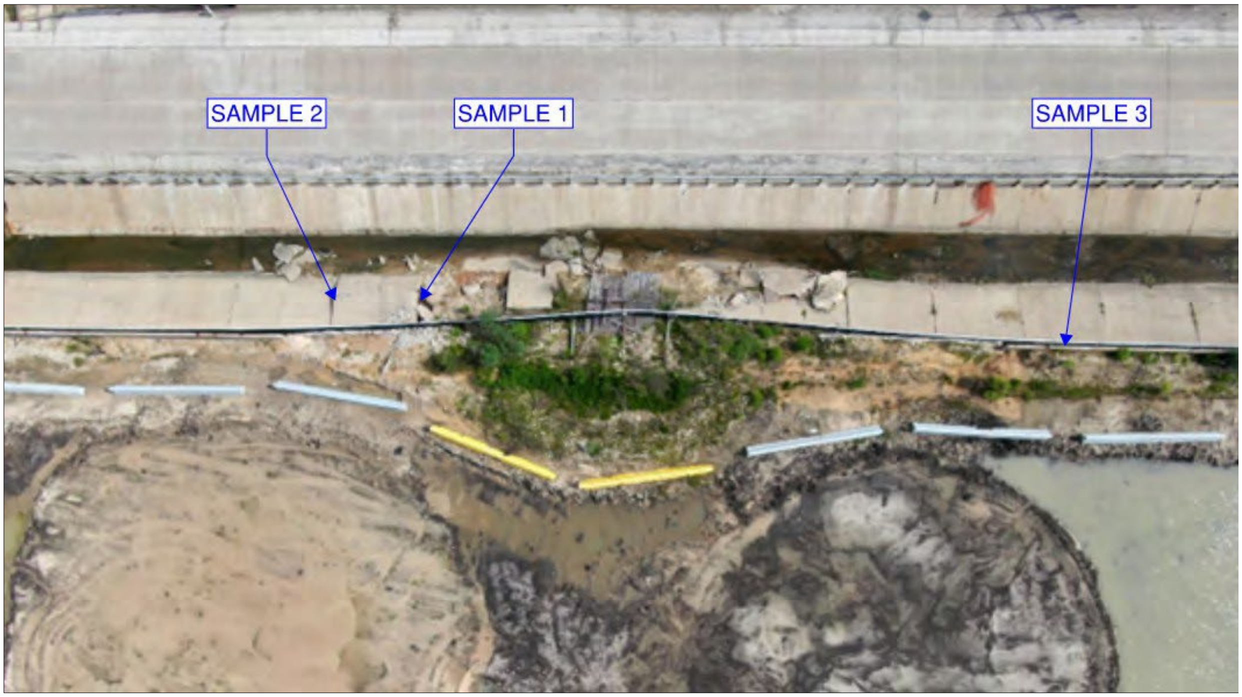

Photo 18: Soil Sample Locations relative to breach in containment wall

Photo 19: Location of Sample 1

Photo 20: Location of Sample 2

Photo 21: Location of Sample 3

Sample 1 appears to be a stiff mottled tan and gray silty deltaic clay. Its classification would be most likely "CH" when classified in accordance with the Unified Classification system. Sample 2 appears to be a dark gray deltaic clay, also likely to be classified as a CH. Sample 3 appears to be a moist soft gray marine clay CH. Both Samples 1 and 2 appear to have been disturbed and are poorly consolidated, whereas Sample 3 is fine grained and well consolidated. Samples 1 and 2 are assumed to be typical of the soils located underneath the sloped side slab of the drainage ditch. Sample 3 is assumed to be similar to the soils inside the containment area at the containment wall. The soil in Samples 1 and 2 appears to be moderately sensitive. Soil sensitivity is a characteristic describing the loss of soil strength when changing from an undisturbed natural condition to a disturbed condition through excavation and re-compaction. Soils with higher sensitivity lose a greater proportion of their strength when disturbed. Sample 3 appears to have a high shrink-swell potential, or a potential to change volume as water content in the soil changes. Soil swelling can increase the pressure on retaining walls considerably higher than normal pressures.

Observations from Excavation

ITC excavated a section of the interior face of the containment wall on June 9, 2022. Atlas Engineering was unable to visit the site during the excavation, however CSB personnel were able to observe the condition of the wall after the excavation and take measurements (Photos 22 & 23). Measurements taken in the excavation area were used to refine the cross-section sketch through the containment wall shown above in Figure 3. The excavation revealed the containment wall extends down 4 feet below the grade level of the interior of the tank farm. There was a horizontal slab extending approximately 5 feet south from the interior face of the containment wall. This slab had a highly irregular edge and bottom surface, indicating it was cast against grade. No standing water was seen in the footing, indicating the natural groundwater level was below the base of the footing. The excavation also revealed the location of an underground firefighting water distribution pipe that supplied the fixed firefighting monitors located along the north wall inside the tank farm.

Photo 22: Containment wall footing excavation, south face of north wall, inside containment area

Photo 23: Containment wall footing and underside of footing

A contractor was utilized to perform a ground penetrating radar (GPR) scan of the foundation in an attempt to determine if reinforcement was present in the foundation and its general configuration. Due to the irregular surface of both the top and bottom of the concrete footing, the GPR instrument was limited in the information it could provide. The depth of the concrete could not be definitively identified due to the irregularities of the bottom surface of the concrete, a result of being cast against grade. GPR did indicate the presence of reinforcement in the concrete foundation, running both longitudinally and across the slab.[18] GPR was not able to identify if any dowels existed between the horizontal concrete slab serving as the footing and the vertical concrete wall forming the containment wall. Longitudinal reinforcement was detected approximately 12-inches on center, while transverse reinforcement was detected with spacings varying from 6 to 8-inches on center (Figure 4). The size of the reinforcement could not be determined from the GPR results. Excavation on the exterior side of the containment wall was not possible due to the presence of active pipelines in the area.

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[18] Holes Technology LP Report, "Ground Penetrating Radar of Concrete Slab" June 16, 2022

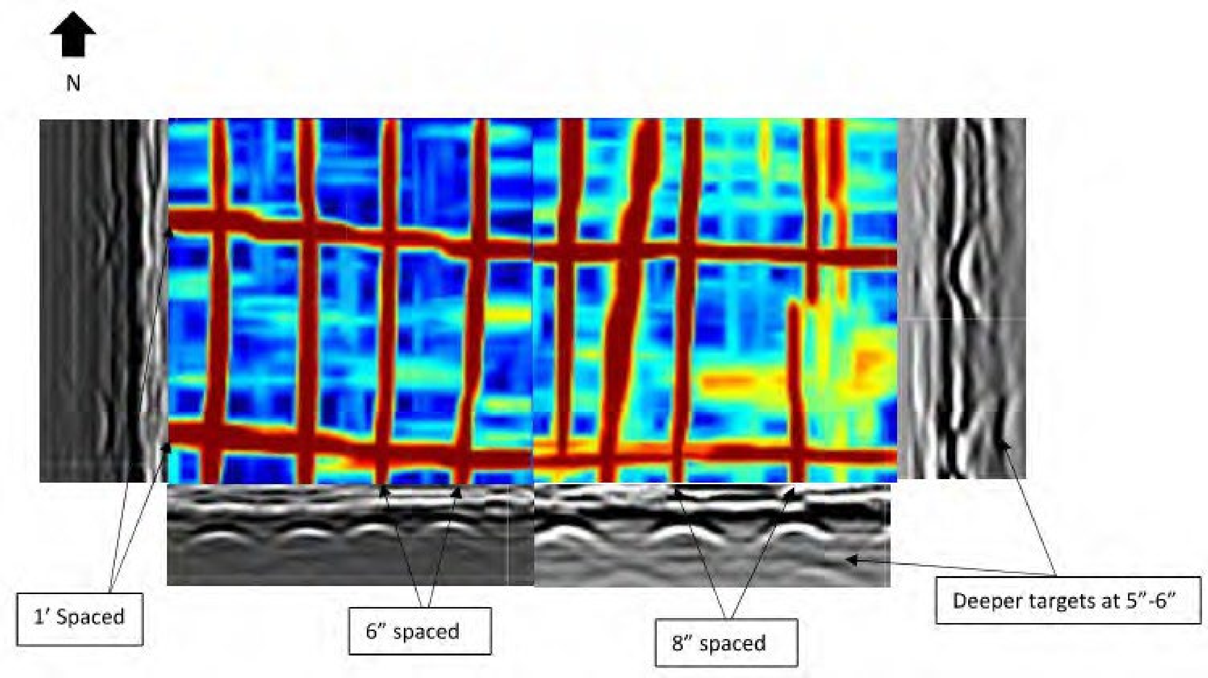

Figure 4: GPR scan results of retaining wall foundation slab from Holes Technology LP Report

Conclusions

Our conclusions are based on the photos, videos, and documentation provided by the CSB to Atlas Engineering and the limited information that could be gathered from the site after the event, after remediation efforts had been performed. The conclusions of this report are based on the timeline of the failure, the displacement seen in photos and videos from the event, general knowledge of the soil materials, and an understanding of the construction methods involved.

The Jensen Hughes report, "Perspectives on Tank Farm Fire – ITC Deer Park (Texas) Facility", has a thorough discussion on the applicable codes to the design of facilities for the storage of flammable liquids. They mention that NFPA 30, "Flammable and Combustible Liquids Code" from 1969, is the most applicable standard the containment area should have been designed to. In that edition of NFPA 30, containment structures are required to meet a number of conditions, including: designed to contain the maximum volume of the largest container in the area, designed to a liquid-tight condition, to withstand full hydrostatic head of the walls, have an average wall height of 6 feet or less above interior grade, and maintaining separation between containers by either drainage or curbs. The Jensen Hughes report also covers the issue of drainage and separation between vessels. Our observations at the site established that the wall was of adequate height to meet NFPA requirements for capacity and total height, and contained waterstop detailing in an effort to maintain a water-tight wall.

The containment wall displaced as a solid unit, with the photos provided from the incident showing the wall remained straight and continuous between construction joints. The vertical construction joints at the wall contain waterstops and a basic shear-key cast into the concrete joint, which would likely be adequate if the base of the wall did not shift laterally. It is unknown if there were construction joints in the footing at the same location as the wall, nor is it known if the reinforcement indicated by GPR in the footing was continuous across any joints. Doweling or tension reinforcement across the construction joints of the wall might have improved the global integrity of the wall, but likely would not have prevented the observed failure.

During the breach in the containment wall, the sloped slabs of the drainage ditch buckled upward, indicating either a large upward force from soil and hydrostatic water pressures or a large lateral force from lateral sliding of the containment wall. The sloped sidewalls of the ditch were not directly connected to the containment wall, with a gap between the top of the slab and the containment wall of at least 2- feet. Nor were the sloped slabs sized or reinforced in any way that indicates they were intended to brace the containment wall. Their construction appears to be designed to prevent erosion of the soil forming the drainage ditch only.

As standing water is not evident in the drainage ditch, it can be assumed that the groundwater's phreatic surface is below the ditch, therefore the soils natural moisture content is unsaturated at elevations above the bottom of the drainage ditch. Fire suppression efforts resulted in water and chemicals flooding the containment area and were left in place filling the area with liquid for several days prior to failure of the containment wall. Liquid levels inside the containment area could have potentially been as high as 4 feet above grade at the time of the containment wall failure.

Our observations determined that to construct the wall, the likely sequence required: excavation to cast the footing, installing wall formwork, setting reinforcing steel, and placing concrete in the forms for the containment wall. After the concrete was sufficiently cured, the forms would have been removed, backfill would have been placed to fill the excavation on both sides of the wall, and fill would be placed to construct the tank pad. If the native soils were of sufficient quality, they were often used as backfill material requiring compaction of the fill to specified degrees of compaction within a moisture-compaction range. Where native soils were not of sufficient quality, borrow soils would have been brought in for backfill. Achieving an adequate degree of compaction adjacent to a relatively thin retaining wall is difficult, as the energy required for compaction, if applied too close to the wall, may damage the concrete wall. In addition, compacting backfill in a narrow trench, such as the one likely excavated for the firefighting water line, would also have been difficult. Compaction of soil around a pole set in the ground, such as the light pole in the area of the wall failure, is especially difficult. Inadequate compaction would result in excessive void space in the soils and not adequately seal the interface between the structures and the soils.

It is unknown what the intended soil elevation and slope for the side of the concrete wall outside of the containment area was for the original design. Proper retaining wall design must include the geometry and condition of the soil on both sides of the retaining wall. With no design documents available, it is unknown if the current geometry of the soil outside the wall matches the original design geometry for the containment wall. If the concrete lining to the drainage ditch was added after the construction of the containment wall, as aerial imagery suggests, it is possible that the soil geometry outside the wall was changed, perhaps significantly. It is reasonable to assume that the drainage ditch may have been enlarged to handle increased stormwater flows as the general area continued to develop. This could have resulted in less soil being present outside the containment area against the wall. The soils that are on the outside of the wall contribute greatly to ability of the wall to resist lateral pressures. The concrete slabs formed to line the drainage ditch primarily served to prevent erosion of soil as stormwater flowed through the ditch. The slabs do not appear to have been designed to buttress the containment wall.

If water is introduced to poorly compacted backfill, it will more readily absorb into the soils. As the soils become more saturated, they weaken. That loss of strength combined with the increased wet unit weight of the soils, ever increases the lateral earth pressure against the wall and the sloped slabs of the drainage ditch. This additional pressure can be greater than twice the design pressure, possibly overloading the wall or causing the drainage ditch concrete slabs to buckle upward. In addition, as the wall or slab deflects or displaces and the soils continue to fail, tension cracks can form in the soils allowing even more water into the backfill, further weakening the soil and further increasing the lateral pressure against the wall.

As mentioned above, the interface between the soils and the concrete is typically the most problematic for soil erosion due to the difficulty in achieving adequate compaction immediately adjacent to the wall. Not only will the poorly compacted zone settle over time, creating pockets for the water to collect and infiltrate, but the high volume of pore space will provide conduits for water to infiltrate. This water will collect then move through the soils, picking up fine particles along the way creating tubes, referred to as “piping”. These tubes act as open conduits for freely flowing water and can eventually erode the subsurface sufficiently to undermine the wall structure and bring hydrostatic pressures to bear.

The failure of the containment wall appears to be related to the soil conditions supporting the wall. The containment wall primarily displaced laterally, with the lateral movement due to excessive lateral soil and hydrostatic pressures and inadequate soil resistance on the outside of the containment wall and inadequate sliding resistance of the footing. Based on on-site observations and examination of the soil samples, the following opinion is offered as the most probable scenario under which the initial failure of the containment wall may have occurred.

It is most likely that less than optimum on-site soils were used as backfill. CH soils are difficult to manage within a suitable moisture compaction range and, as they are highly plastic in nature, they often fail and deflect excessively under standard compaction effort. It appears that it was difficult to achieve an adequate degree of backfill compaction at soil/structure interfaces, such as along the containment wall, water line, and light pole. With potential for as much as 4-feet of fire suppression water retained in the containment wall for days, this possibly led to saturation of the soils and increased lateral earth pressures against the containment wall.

As the wall deflected due to the excessive lateral earth and hydrostatic pressures, the construction joints began to open, tearing the waterstop material and increasing the velocity of the escaping water. As the water velocity increased, the erosion of the soils at the joint and beneath the sloping slab subgrade accelerated and piping increased, increasing the hydrostatic pressure, eventually lifting and damaging the thin drainage ditch slab that lined the slope. In addition, as the wall shifted outward, it further damaged the sloped slab. Eventually, it appears that pieces of the slab were washed out of place by the final torrent of escaping liquid.

Lessons Learned

From the information reviewed for this report and the conclusions inferred, the following lessons learned were developed..

1. Classify containment structures and drainage structures as systems critical to fire safety and emergency response.
2. Preserve design and as-built documentation for containment structures, including site grading plans. Make this documentation accessible for future review. Include containment structures as a system to be reviewed when conditions change at the site.
3. Assess the impacts of adjacent construction, both inside and outside the containment area, to the strength and stability of containment structures. When containment structures are close to a property line, review how changes to adjacent property may affect support conditions of the containment structure.
4. Design containment walls for fully saturated soils on both sides of the wall. Design for maximum hydrostatic head on the interior of the containment wall assuming all soils are saturated.
5. Incorporate water stop features to develop full continuity of systems. Pay special attention to terminations or transitions between systems, such as where footing-to-wall joints meet wall construction joints.
6. Provide robust structural continuity across construction joints, particularly shear and tension continuity.
7. Ensure adequate compaction of suitable backfill to the structures edge with careful construction technique. Verify acceptable compaction by inspection of compaction results. Ensure adequate compaction of excavations for ancillary items located in proximity to containment structures. If achieving adequate compaction is not practical, other methods such as placement of flowable fill for backfill, pressure grouting along the soil/structure interface, or installation of HDPE membranes lapped below the backfill then up along the soil/structure interface should be considered to reduce the potential for subsurface erosion.

END OF PERSPECTIVE