FLAMMABLE LIQUID TANK EXPLOSION

Phoenix, AZ

November 15, 1984

NFPA INTERNATIONAL

FIRE INVESTIGATIONS

NATIONAL FIRE PROTECTION ASSOCIATION

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NATIONAL FIRE PROTECTION ASSOCIATION

INTERNATIONAL

Investigation Report

Flammable Liquid Tank Explosion
Phoenix, Arizona
November 15, 1984
Fire Fighter Fatality

Prepared by

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In Cooperation with

Federal Emergency Management Agency/
United States Fire Administration

and

National Bureau of Standards/
Center for Fire Research

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This investigation was conducted by the National Fire Protection Association (NFPA) under an agreement with the Federal Emergency Management Agency/United States Fire Administration (FEMA/USFA) and the National Bureau of Standards/Center for Fire Research (NBS/CFR). The investigation was jointly funded by these agencies and the NFPA.

ABSTRACT

On November 15, 1984, the Phoenix, Arizona Fire Department responded to a rescue call at a small petroleum bulk plant. A worker, involved in a toluene tank cleaning operation, was overcome in the tank. During rescue operations, that utilized a gasoline engine driven power saw, an explosion occurred resulting in the death of one fire fighter and injury to 16 other fire fighters. The worker died of asphyxiation and inhalation of toluene vapors.

This incident emphasizes the need for recognition of both the flammability and toxic properties of hazardous materials at fire and rescue scenes and the application of appropriate procedures.

INTRODUCTION

The National Fire Protection Association (NFPA) investigated the Western States Petroleum, Incorporated bulk plant incident in order to document significant factors relative to the explosion and resulting fire fighter casualties.

This study was conducted under a major fires investigation agreement between the Federal Emergency Management Agency/United States Fire Administration (FEMA/USFA), the National Bureau of Standards/Center for Fire Research (NBS/CFR), and the NFPA. The agreement, funded by FEMA/USFA, NBS/CFR and the NFPA, provides for the investigation of technically significant fires by the NFPA's Fire Investigations and Applied Research Division to document and analyze incident details and report lessons learned for loss prevention purposes.

The NFPA became aware of the fire on the day of occurrence, November 15, 1984. Martin F. Henry, Assistant Division Director, NFPA Engineering Field Services, traveled to Phoenix to document facts regarding this incident. A 3-day, on-site study and subsequent analysis are the basis for this report. Entry to the scene and data collection activities were made possible through the cooperation of the Phoenix Fire Department. This report presents the findings of the NFPA data collection and analysis effort.

This report is another of NFPA's studies of fires having particular educational or technical interest. The information presented is based on the best data available during the on-site data collection phase and during the development of this report. It is not NFPA's intention that this report pass judgment on, or fix liability for, casualties or property loss in this incident.

The cooperation and assistance of Chief Alan V. Brunacini, J. Gordon Routley, Assistant to the Fire Chief, Research and Planning Division, and Bruce H. Varner, Division Chief-Safety Officer, Phoenix Fire Department, is acknowledged and appreciated.

BACKGROUND

The Western States Petroleum, Incorporated bulk plant was located just outside the city limits of Phoenix, Arizona. The small bulk plant portion of the facility was at the rear of the premises with a conventional service station nearer the street. The bulk plant was comprised of 11 storage tanks handling diesel fuel, methanol, solvent, toluene, and several grades of gasoline. The flammable and combustible liquids were delivered to the plant by tank truck and, in turn, distributed to commercial customers in drums by tank truck. The service station was supplied by underground tanks. (See Figure 1.)

Tank No. 10, which had contained toluene, was involved in this incident. It was a welded steel vertical cylindrical cone roof tank measuring approximately 20 feet high by 9 1/2 feet in diameter with a nominal capacity of 10,000 gallons. The steel shell thickness was 1/4 inch. The present owner had operated the facility for six months and, during that period of time, the tank was used exclusively for the storage of toluene. (See Appendix B, DOT and NFPA Information on Toluene.)

The toluene tank was one of four tanks that were located within a cement block wall that served as a dike enclosure. The dike was approximately 32 feet by 45 feet, roughly rectangular in shape, and about 3 feet in average height. The dike capacity, for Tanks 7, 8, 9 and 10, was adequate for the tanks as required by NFPA 30, The Flammable and Combustible Liquids Code (NFPA 30).[1] The dike enclosure contained a collection of old piping,

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[1]NFPA 30 requires that a dike have volumetric capacity sufficient to contain the contents of the largest single tank contained therein. In the interest of comparing this facility to current national consensus standards, NFPA 30 was utilized for discussion purposes.

fittings and valves between tanks 9 and 10 and the dike wall. (This made for difficult footing for the fire fighters operating within the dike in this incident.) Tank spacing within the dike enclosure, from one tank shell to another, was in accordance with the minimum distances required in NFPA 30.

The tank was equipped with a 2 1/2-inch pressure-vacuum vent at the top of the cone roof. The roof also had a 16-inch diameter manway close to the outer perimeter of the roof, and the manway was normally fitted with a bolted cover. There was no emergency relief venting on the tank.[2]

There was a 2-inch threaded drain opening, normally fitted with a cap, at the bottom of the tank shell. There was also a 2-inch opening fitted with piping that ran under the dike wall to the loading rack. The only access to the interior was via the manway opening on the roof, since the tank was not fitted with a bottom manway. At the time of the incident, the roof hatch cover was off, the pressure-vacuum vent was tied open, and the bottom drain was uncapped. There was residual toluene in the tank up to the bottom of the drain opening, approximately 4 inches in depth.

It was reported that the hatch cover and drain had been removed in the morning in order to rid the tank of vapor by means of natural ventilation in anticipation of cleaning the tank in the afternoon. No further action of any kind was taken to expel vapor from the tank.

The weather on November 15th was very sunny and dry. Temperatures rose steadily during the day from 55°F at 0800 hours to 76°F at 1400 hours. At 1500 hours the temperature remained at 76°F and the humidity was 27 percent.

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[2]This was not in accordance with NFPA 30, but this was not of major significance in this incident. The Code requires that aboveground tanks storing flammable liquids be equipped with such vents in order to protect the tank from catastrophic failure due to overpressure.

The City of Phoenix measures just over 380 square miles and is home to an estimated 860,000 people. The Phoenix Fire Department operates 38 engine and 11 ladder companies, with a variety of special units, and has 1016 employees. The Department responded to over 75,000 alarms in 1984, including over 50,000 emergency medical service calls. The annual operating budget is over $40 million.

The unincorporated areas around the City of Phoenix are protected by the Rural/Metro Fire Department, Inc., a private corporation which operates in Arizona and other states. The specific area where the bulk plant is located is within a fire district which, in turn, contracts with Rural/Metro to provide services. The Phoenix city limits were directly across the street from the plant.

In this incident the call was received by the Phoenix Police Department which immediately relayed the information to the Phoenix Fire Department. The Phoenix Fire Department responded and also advised Rural/Metro of the call in their jurisdiction. The policy of the Phoenix Fire Department, at that time, was to respond to life threatening emergencies, where Phoenix units were closest, and to advise the proper jurisdiction also to respond.

THE INCIDENT

Prior to 1500 hours, two workers went to the roof of the tank using a metal ladder to gain access. They brought along one 30-minute self-contained breathing apparatus (SCBA) and a spare cylinder that had been rented that day. A 1/4-inch nylon rope, a squeegee-type mop, and

paper towels were also brought to the roof. The rope was tied at mid length around the pressure-vacuum relief vent at the top of the cone roof, and one end was lowered into the tank. During the NFPA study of the incident, the exact plan of action was not determined. However, given the fact that the worker would have to move hand under hand down this rope, it may have been that he intended to go to the bottom of the tank and then have the SCBA lowered to him. He had removed his sneakers and left them on the roof prior to making entry, barefoot and without protective clothing or respiratory protection. The victim was overcome very quickly after entering the tank. He was on the floor of the tank, overcome by the lack of oxygen and the presence of the toluene vapors. The other worker on the roof reportedly lowered the SCBA to him and touched him with it, but the worker in the tank did not respond to this action. The man on the roof yelled to other employees at the facility to call for assistance. The precise time of the man's entry into the tank was not determined.

The initial call was made to the Phoenix Police Department and relayed to the Phoenix Fire Department 1 minute later at 1502 hours. Phoenix Fire Communications advised Rural/Metro of the incident and also dispatched Phoenix units, due to their faster response time to this location. The Rural/Metro Fire Department also responded, arriving several minutes after the Phoenix companies, and two Rural/Metro fire fighters assisted in the rescue attempt.

Companies from Phoenix were dispatched to the scene at 1504 hours. The initial response included first due Engine 39, in addition to four units from the Hazardous Materials Emergency Response Team; Rescue 3, Engine 4, Ladder 4 and Support 4. A battalion chief and a deputy chief were also dispatched. Engine 39 radioed their arrival at 1509 hours.

Engine 39's complement included a captain, an engineer, and two fire fighters. Information provided to the Fire Department indicated that the man in the tank was believed to be conscious and on his back at the tank bottom, with his face out of the product. The fire fighters were unable to see him through the open manway or hear any sounds from him. The personnel from Engine 39 arranged extra SCBA compressed air cylinders to discharge air into the tank to provide ventilation for the victim. The cylinders were placed on the ground, and valves opened to discharge air into the open drain fitting. At 1512 hours, Rescue 3, with a two-man paramedic team, arrived on the scene.

During initial radio communications there was some mispronunciation of the product name which caused confusion and delay in researching its properties, although it was confirmed as toluene within a few minutes. At 1514 hours, a radio transmission from Engine 4, which was approaching the scene, advised that SCBA should be used by fire fighters operating on top of the tank if the product was toluene. Receipt of this message was acknowledged by Engine 39, and the company further acknowledged that the fire fighters had been instructed "not to go down."

At 1515 and 1516 hours, respectively, Engine 4 and Ladder 4 arrived at the scene. Engine 4's complement was one captain, an engineer and three fire fighters. Ladder 4 arrived with a captain, two engineers and one fire fighter. Support 4, a special equipment driven by an engineer, arrived with Ladder 4.

At 1515 hours, Engine 4 notified the dispatcher that there was no product in the tank, that they were dealing with a "toxic material," and that they were possibly going to cut into the tank for entry. Ladder 4 was asked, on arrival, to bring its gasoline engine driven power saw,

with a steel cutting blade, to the tank. The decision to cut into the tank was based on an assessment that this approach would reach the victim more rapidly than any other and could be accomplished safely.

A 1 1/2-inch handline was stretched and operated through the roof manway to cool cutting sparks inside the tank, and a second 1 1/2-inch handline was operated on the outside. The handline, operating into the tank through the manway, was intended also to provide ventilation by causing fresh air flow into the tank. All of the personnel operating in the immediate area of the tank were using SCBA, and wearing state-of-the-art helmets, protective hoods, protective coats, gloves and 3/4-length boots.

Using the power saw, the first cut was made vertically, running 19 inches in length, to a point 3 feet 7 inches above the tank bottom. The second cut was also vertical, 18 inches to the left and parallel to the first, beginning at the same height and running 14 inches in length. The third and, as it turned out, final cut would be made horizontally at the top to connect the two vertical cuts. The saw operators spelled each other during the operation, with a different member performing each of the three cuts. The outside handline was used intermittently to cool the cutting operation, but was stopped several times because it interfered with the saw.

An oxyacetylene torch was brought into the dike area, in consideration of using it to speed up the effort. However, at 1540 hours, the deputy chief, who had arrived and assumed command of the incident, ordered that the torch not be used. The deputy chief was made aware of the potentially explosive nature of the product inside the tank and expressed his concern to the sector officer (from the Hazardous Materials Response Team), who was directing operations inside the diked area. The sector officer indicated that he was aware of the hazard.

Concerned with the flammability hazard, the deputy chief directed the sector officer to remove the personnel operating the interior handline from the top of the tank. The line was shut down and the personnel descended to ground level. At 1537 hours, a second ladder company (Ladder 22) arrived in response to a special call in order to have its power saw available for use. During this same approximate time, a small fire was seen about 30 feet to the west of the cutting operation, near the loading rack. The fire was probably started by sparks from the saw, and it involved a small amount of flammable liquid near a product pump. It was described as a "lazy fire" at ground level a few inches high. The exterior handline, which was not being used for cooling at that time, was diverted momentarily toward the fire, while a person standing in the vicinity also began to stomp on the fire.

At this moment a vapor ignition occurred inside the tank. A light colored flame shot up through the open hatch on the roof, and the partially cut section of the tank was blown outward and bent downward in about a 75-degree angle from the tank. The flame at this opening was bright orange and of greater intensity than the flame at the hatch opening. The ignition was accompanied by a whooshing sound and a muffled bang. The duration of the ignition was less than a second, but pressure within the tank was sufficient to distort the tank bottom so that the tank shell was 5 to 9 inches off its concrete base. The flat bottom plate became rounded. In addition, the roof was distorted and extended so that its cone shape was wrinkled and rounded rather than cone shaped.

The main force of the vapor ignition was directed out of the shell where the cut was being made. The fire fighter operating the saw was thrown to the dike wall and landed near empty drums. The saw was hurled through the air against the side of Engine 39. The fire fighter, who was

backing-up the saw operator, was thrown against the dike wall and received massive head and internal injuries, and also some burns. He was killed instantly from the force of the explosion. Several other fire fighters were hurled up to about 10 feet beyond the dike enclosure. In all, 16 fire fighters were injured in addition to the fatality. The force of the ignition blew off helmets and in some cases tore open protective clothing worn by the men. The intensity of the heat caused some damage to the protective hoods of the men nearest the blast. Fourteen of the injured were treated and released. Two were kept in the hospital, one overnight and the other for two nights. Injuries included burns, fractures, lacerations and effects of the concussion.

Following the ignition, all emergency efforts were directed toward medical treatment and evacuation. The fire did not continue burning after the explosion. Later, when it was determined that there was no danger of further ignition, the body of the man inside the tank was retrieved. An autopsy revealed only minor burns to one arm, and it was determined that the cause of death was asphyxiation and inhalation of toluene vapors. Time of death, determined by the autopsy, was estimated to have occurred within 10 minutes of his entry into the tank. (This indicates that he may have died at about the time the fire department arrived, but certainly before the cutting operation got underway.)

ANALYSIS

In this incident, a worker was overcome in the toluene tank following entry for cleaning purposes. Although the details of procedures used by the workers were not determined during the NFPA study, the facts indicate that accepted industry procedures for safe tank entry were not followed.

The worker was overcome, indicating that the atmosphere in the tank was not safe for entry without breathing apparatus; and a quantity of toluene was at the bottom of the tank so flammable vapors were also present. These conditions resulted in the rescue call and fire department response.[3]

During the rescue operation a decision was made not to attempt entry through the manway to rescue the victim, due to the narrow opening making entry with SCBA and protective clothing difficult. The explosion occurred, apparently by the ignition of flammable liquid vapors inside the tank, during the cutting operation utilizing a gasoline engine driven power saw. The ignition is believed to have been caused by cutting sparks from the abrasive saw blade. Unfortunately, one fire fighter died as a result of the explosion and 16 others were injured.

The injuries sustained in the incident would have been more numerous and severe were it not for the fact that the fire fighters were outfitted with state-of-the-art protective clothing and equipment, and were trained to make use of such equipment at appropriate times.

Emergency procedures for removing a victim overcome inside a tank generally involve sending rescue personnel into the tank via the same opening used by the victim. This involves entry by personnel with SCBA or airline-supplied respirators, and secured by harness or life rope. The victim would then be hoisted out of the tank using the rescue rope and a harness or wrist straps. This can often be accomplished rapidly,

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[3]See Publications No. 2015 Cleaning Petroleum Storage Tanks and No. 2217 Guidelines For Confined Work in the Petroleum Industry available from the American Petroleum Institute. Also see Criteria For a Recommended Standard for Working in Confined Spaces, available from the National Institute of Occupational Safety and Health.

but the size of the opening may restrict the use of protective clothing and SCBA. If full protective clothing is not used, the rescuers may be exposed to toxic chemicals through skin contact, depending on the product involved. SCBA must always be worn or airline-supplied respirators used. There is a trade-off involved between risk to the rescuer and speed in reaching the trapped victim.

Use of the rooftop manway in this incident would have been difficult. The small diameter of the opening (16 inches) made entry difficult with protective clothing and SCBA. The work area available on top of the tank was also very limited. This alternative was considered and rejected in favor of the cutting option.

Where flammable vapors are present in a tank, as was the case here, cutting operations using torches or power saws are to be avoided, even if a judgment is made that such an approach might be faster. Ignition of the flammable vapors is a likely consequence. It cannot be assumed that ventilation or water spray application will reliably prevent ignition of the vapors. Testing with proper instruments to evaluate vapor concentrations and oxygen content is the only reliable means to confirm that tank contents are safe for hot work.

This incident emphasizes the need for recognition of both the flammability and toxic properties of hazardous materials at fire and rescue scenes and the application of appropriate procedures.

APPENDIX B
DOT and NFPA Information on Toluene

Excerpts from various references follow,
See source documents for complete information.

1984 EMERGENCY RESPONSE GUIDEBOOK
U.S. Department of Transportation
Identification Number 1294 - Response Guide 27

POTENTIAL HAZARDS

FIRE OR EXPLOSION

Flammable/combustible material; may be ignited by heat, sparks or flames.
Vapors may travel to a source of ignition and flash back.
Container may explode in heat of fire.
Vapor explosion hazard indoors, outdoors or in sewers.
Runoff to sewer may create fire or explosion hazard.

HEALTH HAZARDS

May be poisonous if inhaled or absorbed through skin.
Vapors may cause dizziness or suffocation.
Contact may irritate or burn skin and eyes.
Fire may produce irritating or poisonous gases.
Runoff from fire control or dilution water may cause pollution.

EMERGENCY ACTION

Keep unnecessary people away; isolate hazard area and deny entry.
Stay upwind; keep out of low areas.
Wear self-contained (positive pressure if available) breathing apparatus and full protective clothing.
Isolate for 1/2 mile in all directions if tank car or truck is involved in fire.
FOR EMERGENCY ASSISTANCE CALL CHEMTREC (800) 424-9300
If water pollution occurs, notify appropriate authorities.

FIRE

Small Fires: Dry chemical, CO_2, water spray or foam.
Large Fires: Water spray, fog or foam.
Move containers from fire area if you can do it without risk.
Cool containers that are exposed to flames with water from the side until well after fire is out.
For massive fire in cargo area, use unmanned hose holder or monitor nozzles; if this is impossible, withdraw from area and let fire burn.
Withdraw immediately in case of rising sound from venting safety device or any discoloration of tank due to fire.

SPILL OR LEAK

Shut off ignition sources; no flares, smoking or flames in hazard area.
Stop leak if you can do it without risk.
Use water spray to reduce vapors.
Small Spills: Take up with sand or other noncombustible absorbent material and place into containers for later disposal.
Large Spills: Dike far ahead of spill for later disposal.

FIRST AID

Move victim to fresh air; call emergency medical care.
If not breathing, give artificial respiration.
If breathing is difficult, give oxygen.
In case of contact with material, immediately flush eyes with running water for at least 15 minutes. Wash skin with soap and water.
Remove and isolate contaminated clothing and shoes at the site.

NFPA 325M, Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids

Properties of Toluene:
(See Toluol)

Flash Point: $40^{o}F$ ($4^{o}C$)

Flammable Limits: 1.2 to 7.1

Vapor Density: 3.1

Specific Gravity: 0.9

Suggested NFPA 704 Hazard Identification: Health 2; Flammability 3; Reactivity 0.

NFPA 49, Hazardous Chemicals Data

TOLUENE:
Description: Colorless liquid with aromatic benzenelike odor.

Fire and Explosion Hazards: Flammable liquid. Vapors form explosive mixtures with air. Flammable limits, 1.4% and 6.7%. Flash point $40^{o}F$. Ignition temperature, $997^{o}F$. Liquid is lighter than water (specific gravity, 0.9). Vapor is heavier than air (vapor-air density at $100^{o}F$., 1.2) and may travel considerable distance to a source of ignition and flash back. Not soluble in water.

Life Hazards: Eye and respiratory irritant. Extreme inhalation of vapors may cause death by paralysis of the respiratory center.