CASE STUDY

Mixing and Heating a Flammable Liquid in an Open Top Tank

One killed, two injured

Investigation No. 2006-08-I-IL
April 2007

Universal Form Clamp, Inc.

Bellwood, Illinois
June 14, 2006

Introduction

This incident involved the ignition of a vapor cloud generated by mixing and heating a flammable liquid in an open top tank without adequate safety controls. One contractor was killed and two employees were injured, one seriously. The facility suffered a significant business interruption.

Key Issues:

- Flammable Liquid Process Design
- Engineering Controls
- Plan Review and Code Enforcement
- Emergency Preparedness

INSIDE . . .

1.0 Incident Description

This Case Study describes the ignition of a vapor cloud[1] generated by mixing and heating a flammable liquid[2] in an open top tank without adequate safety controls. The tank was located in the chemical mixing area of the Universal Form Clamp (UFC) facility in Bellwood, Illinois, a suburb of Chicago.

On the morning of June 14, 2006, an operator was mixing and heating a flammable mixture of heptane and mineral spirits[3] in a 2,200-gallon open top tank equipped with steam coils. The finished product, "Super Clean and Tilt," is a proprietary mixture, which is applied to cured concrete surfaces to prevent bonding with wet concrete.

As the operator was adding an ingredient to the batch, he observed a "dense fog" accumulating on the floor below the tank (Figure 1).

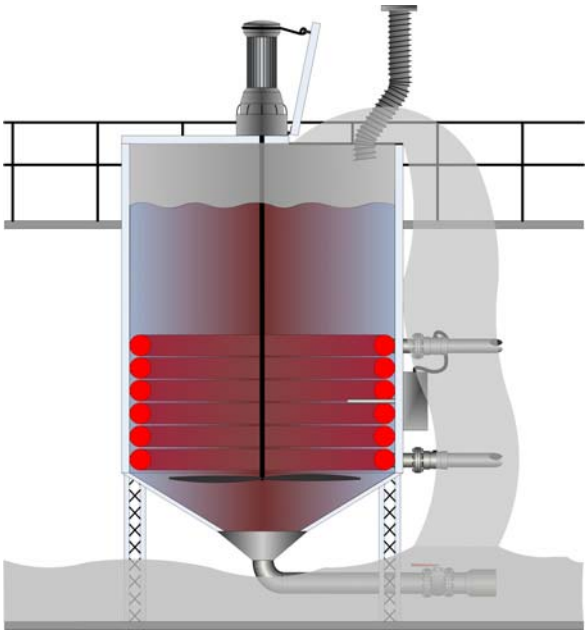

Figure 1. Vapor spilling from top of mixing tank

He immediately notified a senior operator who helped him shut down the operation. They both exited the building and advised workers in adjoining areas to leave.

As the vapor cloud spread throughout the mixing area and surrounding workspaces, other employees exited the building (Figure 2).

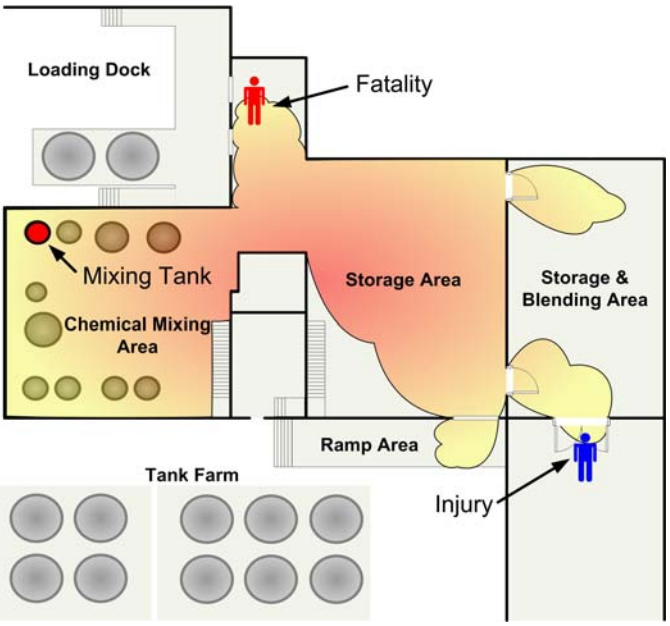

Figure 2. Vapor cloud propagation

Within about 10 minutes after the operator first observed the vapor cloud, most employees who were working in the area had evacuated. A contracted delivery driver passed some of these employees as he walked into the building and into the spreading vapor cloud.[4] The cloud ignited within seconds of him entering. The driver died several days later from the burns he received.

The pressure created by the ignition blew the doors open to an adjacent area, injuring a temporary employee. This employee suffered second-degree burns and was hospitalized for three days.[5]

The Bellwood Fire Department battled a fire confined to a bagged resin storage area for about

[1] This cloud contained vapors and mists, but is referred to as a "vapor cloud."

[2] OSHA defines a "flammable liquid" as any liquid having a flashpoint below 100° F. (37.8° C.), except any mixture having components with flashpoints of 100° F. (37.8° C.) or higher, the total of which make up 99 percent or more of the total volume of the mixture. (29 CFR Part 1910.106(a)(19))

[3] The mixture contained approximately 6,000 pounds of heptane and 3,000 pounds of mineral spirits. The mixture was a flammable liquid. Heptane has a flash point of 25° F (-4° C.), and the flash point for this grade of mineral spirits ranges from 104° F. (40° C.) to 110° F. (43° C.).

[4] Witnesses told CSB investigators that others attempted to warn the driver of the vapor cloud, but he was talking on his cellular phone as he entered the building and did not hear them.

[5] A third employee suffered a minor injury to his arm when he tripped and fell while evacuating.

three and one-half hours.[6] The fire and pressure from the initial ignition produced moderate damage to the structure and interrupted operations for nearly one month. UFC suspended the flammable liquid mixing operation indefinitely.

2.0 Universal Form Clamp, Inc., Operations

UFC manufactures and distributes approximately 3,000 products for the concrete industry. The company has 450 employees at its eleven North American locations. UFC added the chemical mixing area during 2002 and 2003 to produce concrete chemicals, including Super Clean and Tilt. According to company officials, Bellwood was the only UFC facility that mixed and heated flammable liquids.

3.0 Physical Evidence

3.1 Materials Testing

As the operator began adding L50[7] (a non-reactive liquid) to the mixture, he noticed vapor spilling from the top of the tank. To determine if the L50, or any of the other ingredients, could have caused a reaction, independent laboratories tested the mixture and the individual ingredients. This did not identify any reactive materials, indicating that the concurrence of the vapor cloud and addition of the L50 were coincidental.

3.2 Tank Heating System

Performance testing by a contracted testing firm verified that

- the boiler system,[8] under normal operating conditions, delivered enough energy to boil the mixture (221º F, 105º C), and
- there were no leaks in the steam coil inside the mixing tank.

3.2.1 Mixing Tank Temperature Controller

The temperature controller consisted of a liquid-filled temperature-sensing bulb and a pneumatic control unit. It regulated the tank temperature by opening and closing the tank's heating coil steam valves. Because the controller was damaged by the explosion and fire, it was not tested to determine its operability. However, when CSB investigators examined the controller it was found to have not been installed or maintained in accordance with the manufacturer's specifications, which could have caused it to fail or perform erratically on the day of the incident.

The following findings may explain how the temperature controller malfunctioned, and how the vapor cloud was created.

- The temperature-sensing bulb and thermometer well housing (thermowell) did not conform to the manufacturer's specifications.
  - The thermowell, designed to be filled with thermal conductive fluid, was dry, and parts designed to hold the bulb in place were missing (Figure 3).
  - The bulb was not fully inserted into the well (Figure 4).

  Both of these conditions may have contributed to inaccurate temperature sensing or a delayed response, and may have caused the steam valves to remain open long enough to boil the mixture.

- There was a restrictive bend in the liquid-filled capillary tube connecting the sensing bulb to the temperature controller (Figure 4). Fluid inside the bulb must be able to expand and move freely through the capillary tube for the controller to operate properly. This bend may have caused the controller to perform sluggishly or to malfunction.

[6] When the sprinkler system activated, an automatic alarm signal notified the Bellwood Fire Department.
[7] L50 is a proprietary ingredient added to Super Clean and Tilt to enhance its wetting properties.
[8] The boiler system includes the boiler and valves, including high-pressure cutoff switches.

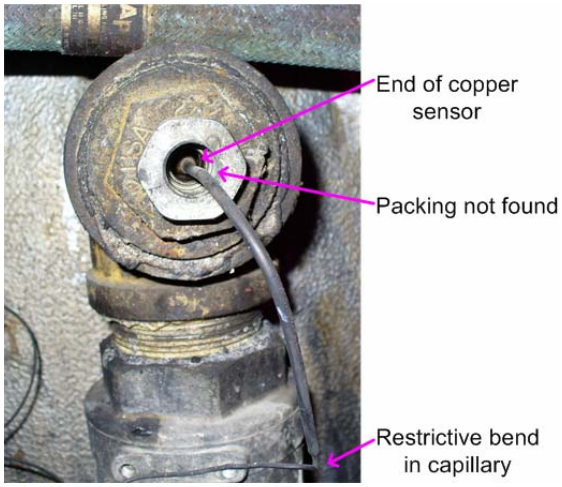

Figure 3. Temperature sensor well

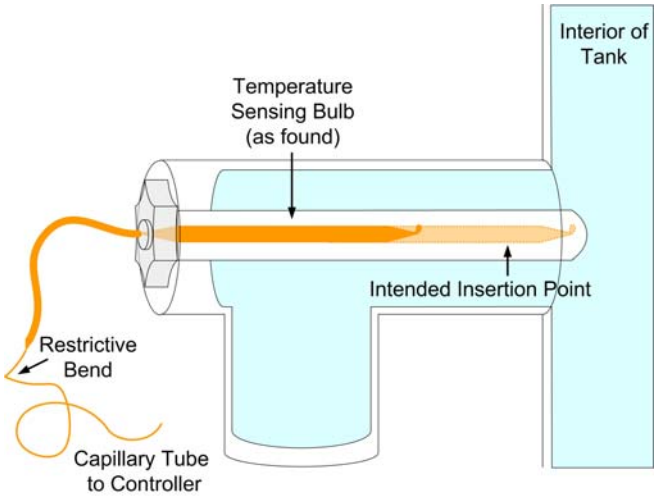

Figure 4. Intended sensor location

- UFC did not filter oil or remove moisture from the "plant air" flowing through the temperature controller. Accumulated oil and/or water, or corrosion caused by humid air may have prevented the controller from operating as designed, allowing the mixture to overheat.

3.3 Temperature Measurement

The process for making Super Clean and Tilt required several hours of mixing and heating. To begin heating, the operator manually opened the steam valves to the tank heating coils and adjusted the temperature controller to maintain the temperature at 164° F (73°C). When the batch process was completed, the operator closed the steam valves and allowed the mixture to cool.

The mixing tank was not equipped with a temperature display or high temperature alarm, and there was no backup shutoff device. The procedure for this mixture required the operator to verify the temperature by climbing the stairs to the upper level to measure it using a hand-held infrared thermometer (Figure 5). If, after checking the temperature, the mixture overheated—as CSB believes occurred in this incident—the operator would not know until the vapors overflowed from the tank.

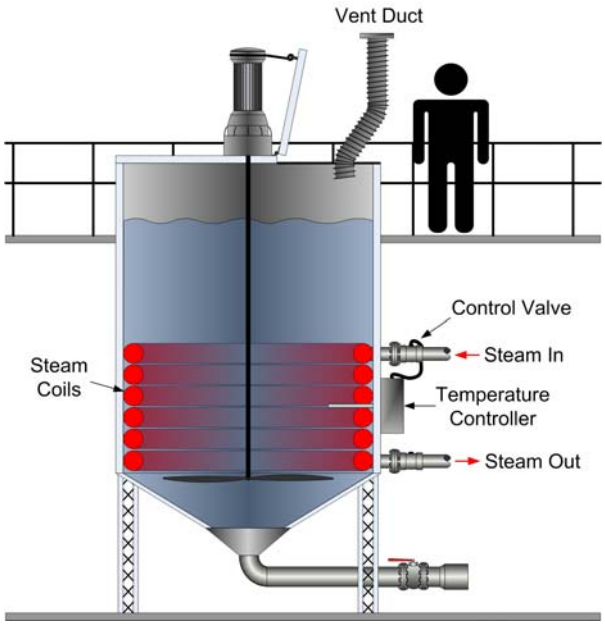

Figure 5. Mixing tank mechanical systems

3.4 Ventilation

The ventilation in the mixing area consisted of local exhaust and area ventilation systems.

3.4.1 Local Exhaust Ventilation

The local exhaust system included two exhaust fans connected to a main duct with flexible ducts extending into the tops of the mixing tanks (Figure 5). This system was incapable of controlling vapors released from the tank because

- both exhaust fan drive belts were broken before the incident, and

- it was not designed to capture and remove a high volume of vapors from an open top tank.

3.4.2 Area Ventilation

The area ventilation system included one supply and two exhaust fans mounted at ceiling level. There were no floor level exhaust registers (floor sweeps) to remove heavy vapors that accumulated on the floor.[9]

Because the exhaust registers were located at ceiling level, and were a significant distance from the top of the tank,[10] the system was incapable of removing tank vapors. Thus, when the mixture boiled, the vapor overflowed the tank and spread along the floor throughout the chemical mixing and surrounding areas.

3.5 Eliminating Ignition Sources

The *Hazardous (Classified) Locations* (29 CFR 1910.307) standard covers the requirements for electric equipment and wiring safety in locations where flammables and combustibles are used.

The mixing room was designed to meet the requirements of 1910.307, but the adjacent area where the vapor cloud migrated and likely ignited, was not. If the design for this process had included the proper safety controls (i.e., local exhaust ventilation, a high temperature alarm, and/or a backup steam shutoff), the vapors would not have overflowed the tank and migrated into the adjacent areas where multiple ignition sources existed.[11]

[9] 29 CFR 1910.106 and NFPA 30 *Flammable and Combustible Liquids Code* (1984 and 2003) require floor-level ventilation for flammable liquid mixing operations.

[10] The nearest exhaust register was approximately 52 feet away.

[11] There were a number of unprotected circuits and motors, including a fork truck, operating at the time of the incident.

4.0 Incident Analysis

4.1 Failure Scenario

The CSB investigators identified the following most likely failure scenario.

- On the morning of the incident, the operator began heating the batch of Super Clean and Tilt in the mixing tank.

- The temperature controller malfunctioned, allowing the steam valve to remain open and heat the mixture to its boiling point.

- The boiling mixture produced a heavy, flammable vapor.

- The ventilation systems failed to remove the vapor and it overflowed the top of the tank, accumulating along the floor of the chemical mixing area.

- The vapor cloud spread into adjacent areas where it was ignited by one of several possible ignition sources.

4.2 Project Design and Construction

UFC hired a professional chemist with concrete chemical production experience to manage the design, construction, and operation of the chemical mixing area. Shortly after his arrival he hired two engineers through a temporary service to work on the construction planning. They reported directly to him, and it was their responsibility to draft the plans for the building permit application.

Despite the credentials of the managing chemist and the two engineers, the process was not designed and constructed in accordance with fire safety codes and OSHA regulations. In addition, mechanical design plans that should have illustrated ventilation and other safety systems were not stamped or reviewed

by a registered design professional before being submitted to the Village of Bellwood.[12]

4.3 Building Permit Application Review

In 2002, when the chemical mixing area was designed and constructed, the Village of Bellwood required new construction permit applicants to comply with the 1990 Building Officials Code Administrators (BOCA) and the 1984 edition of NFPA 30 *Flammable and Combustible Liquids Code*.[13]

In accordance with Village rules, UFC submitted its application to the Village Building Department for review and approval. Because of its flammability issues, the application was forwarded to the Fire Department for review. The Fire Department required UFC to install a fire suppression system, but did not require UFC to comply with other critical safety requirements outlined in BOCA (1990) and NFPA 30. Both of these standards require local exhaust and floor level ventilation, which would have reduced the likelihood of this incident.

4.4 Emergency Preparedness

The two employees who first saw the vapor cloud spilling from the top of the mixing tank shut down the process and warned others in the immediate area to evacuate. However, there was no procedure or system to initiate a facility-wide evacuation. Most of the employees who successfully evacuated, did so only after they saw or smelled the vapor cloud. The delivery driver who died, and those injured, were not aware of the hazard. This incident demonstrates that the facility was unprepared for an emergency release of this magnitude. In fact,

- UFC had no emergency action plan,
- employees had not received emergency action training and had not conducted an evacuation drill, and
- the facility was not equipped with a manually activated employee alarm system.

4.5 OSHA Review

This facility is covered by several OSHA standards that address the conditions that caused this incident. If these standards would have been properly applied, it is likely that the death and injuries may not have occurred.

4.5.1 Flammable and Combustible Liquids (29 CFR 1910.106)

This standard, published in 1974 and based on NFPA 30, *Flammable and Combustible Liquids Code* (1969), applies to the design, construction, storage, and use of flammable and combustible liquids. It does not specifically prohibit mixing and heating flammable liquids in an open top tank. However, because of the increased risk of fire and explosion, the standard requires safeguards to control flammable vapors and mists. These safeguards include installing properly designed local exhaust and floor level ventilation (floor sweeps), and ensuring that electrical equipment and wiring meet minimum safety requirements. This standard does not require industrial facilities that use flammable liquids to have written emergency action plans or employee alarm systems.

Since 1974, NFPA 30 has undergone six major revisions. The 2003 edition requires a written emergency action plan, including procedures and a schedule for conducting drills, and an emergency notification system.[14]

[12] The Village of Bellwood did not require building permit applicants to have their plans stamped or reviewed by a registered design professional prior to submitting them, despite having adopted building codes that required it.

[13] As of June 2006, the Village requires applicants to comply with the International Building Code Series and the 2000 edition of NFPA 30.

[14] NFPA 30 (2003), Chapter 7, Sections 7.12.4 and 7.13.4.

4.5.2 Process Safety Management of Highly Hazardous Chemicals (29 CFR 1910.119)

The *Process Safety Management* (PSM) standard provides a structured program for a systematic approach to chemical process safety and the prevention of catastrophic incidents. It applies to facilities that use certain highly hazardous chemicals and flammable gases and liquids above a specified quantity. The quantity of the mixture involved in this incident triggered the compliance requirements of the PSM standard.[15] However, at the time of the incident, UFC had not implemented a program to comply with this standard.

The PSM standard requires adherence to 14 elements of safety management. The elements relevant to the findings of this investigation are:

- 1910.119(e) *Process Hazard Analysis* (PHA) – a PHA is an organized and systematic effort to identify and evaluate the hazards associated with a specific process. OSHA requires facilities to perform an initial PHA on every covered process, and revalidate it at least every 5 years to ensure it remains relevant.

  A PHA performed by a competent team would have identified and evaluated the hazards associated with the flammable mixing operation. It likely would have identified the lack of critical safety devices such as local exhaust ventilation, a high temperature alarm, and/or a backup steam shutoff system that would have greatly reduced the likelihood of this incident.

- 1910.119(j) *Mechanical Integrity* – this section requires a written program to maintain the on-going integrity of critical process equipment such as piping and valves, temperature controllers, and emergency shutdown systems. It requires regular documented inspection and testing procedures that follow accepted and generally recognized good engineering practices.

  A mechanical integrity program could have identified the problems with the mixing tank temperature controller and alerted UFC to the need to repair it

- 1910.119(n) *Emergency Planning and Response* – this section requires a plant-wide emergency action plan that meets the requirements of OSHA 1910.38 Emergency Action Plans. UFC did not have such a plan.

4.5.3 Emergency Action Plans (29 CFR 1910.38)

This standard outlines the requirement for, and contents of, an emergency action plan (EAP). EAPs are mandatory only when another OSHA standard requires it.

The OSHA standards that are applicable to the flammable mixing operation at UFC, and which require an EAP are

- 29 CFR 1910.119 *Process Safety Management of Highly Hazardous Chemicals*,
- 1910 CFR 1910.120 *Hazardous Waste Operations and Emergency Response*, and
- 1910.157 *Portable Fire Extinguishers*.

Despite its emphasis on flammable and combustible liquid safety, OSHA 1910.106 *Flammable and Combustible Liquids* does not require an EAP.[16]

As a minimum, an EAP must contain procedures to address

- fire and emergency reporting,
- emergency evacuation and identifying exit routes,
- non-evacuated employees who remain behind to operate critical plant equipment,
- head count for all employees after evacuation,

[15] At the time of the incident, the mixture was approximately 9000 pounds. However, the batch recipe called for additional ingredients that would have exceeded the 10,000 pound PSM threshold for flammable liquids.

[16] OSHA 1910.106, based on NFPA 30 (1969), does not require an EAP. However, NFPA 30 (2003) does require an EAP, and requires the EAP to include procedures and schedules for conducting drills. See NFPA 30 (2003), Section 7.12.4.

- employees performing rescue and medical duties, and

- employees needing more information about the plan or to support their duties under the plan.

1910.38 also requires the employer to train employees on the plan requirements and install an employee alarm system in accordance with 29 CFR 1910.165. It does not contain a requirement for employee evacuation drills.[17]

If UFC had implemented the EAP and employee alarm system required by this standard, it is likely that all employees would have been safely evacuated from the facility and the fatally injured delivery driver would have been prevented from entering the building.

4.5.4 Hazardous Waste Operations and Emergency Response (29 CFR 1910.120)

The *Hazardous Waste Operations and Emergency Response* standard (HAZWOPER) applies to facilities where there is a threat of a hazardous substance release. It outlines two choices for an employer. The employer can

- require its employees to respond to releases, but must implement the rigorous emergency response requirements in the standard, or

- it can require all affected employees to evacuate to a safe distance and rely on an outside response agency (e.g., the local fire or Hazmat department).

Employers who evacuate their employees and have an outside agency respond to hazardous substance emergencies are exempt from HAZWOPER, provided they develop an emergency action plan that complies with 29 CFR 1910.38.

UFC did not have an emergency action plan, and had not trained its employees on actions to take in response to a hazardous substance release.

[17] The OSHA website "eTools Home" *Evacuation Plans and Procedures* says "…it's a good idea to hold practice [evacuation] drills as often as necessary to keep employees prepared."

4.5.5 Portable Fire Extinguishers (29 CFR 1910.157)

This standard requires employers who provide portable fire extinguishers to provide initial and follow up training to employees expected to use them. If, however, an employer does not intend employees to use the portable extinguishers, and instead requires employees to evacuate, the employer must comply with the EAP requirements of 1910.38.

Although portable fire extinguishers were mounted on the walls throughout facility, UFC had not conducted required employee training, and did not have an EAP or an employee alarm system in place. While the lack of fire extinguisher training did not contribute to the causes of this incident, the death and injuries may have been prevented if the facility would have had an EAP and an employee alarm system.

4.5.6 Hazardous (Classified) Locations (29 CFR 1910.307)—See Section 3.5

5.0 Lessons Learned

5.1 Project Design and Management

UFC designed and constructed a flammable liquid heating and mixing operation using an open top tank without adequate safety controls in place. Facility managers did not follow regulatory requirements or good engineering practices. A mechanical failure caused the mixture to overheat, which produced a flammable vapor cloud that ignited and killed one and injured two.

A design professional – i.e., a competent engineer, or person knowledgeable in the applicable building codes, regulations and consensus standards – should manage the design and construction of a facility that uses flammable liquids.

5.2 Building Permit Code Review

The Village of Bellwood municipal rules required UFC to comply with BOCA and NFPA codes and standards. However, during its permit application review the Village did not ensure such compliance, and did not require UFC to utilize a registered design professional.

An experienced code reviewer knowledgeable in flammable and combustible liquid safety should thoroughly review facility design plans submitted to the Village.

Alternatively, in lieu of conducting a comprehensive code review, which may be impractical for a small municipality, the Village may require permit applications involving flammable and combustible liquids to include design and construction plans prepared by, and bearing the stamp of, a registered design professional.

In either case, the Village should inspect the completed project to verify conformance with approved plans.

5.3 Emergency Actions and Alarms

UFC had no emergency action plan, employees had not received any emergency action training or conducted an evacuation drill, and the facility was not equipped with an employee alarm system. Seconds before the vapor cloud ignited, the fatally injured contract driver walked through the loading dock area into the vapor cloud as it ignited. In addition, the employee who was seriously burned was unaware that he needed to evacuate, even though others working nearby had left because they saw or smelled the vapor cloud.

Facilities handling flammable and combustible liquids should implement an Emergency Action Plan and practice evacuation drills at least annually, but more frequently if necessary to keep employees prepared.

6.0 Recommendations

6.1 Occupational Safety and Health Administration

2007-08-I-IL-R1

Amend 1910.106 *Flammable and Combustible Liquids* to require facilities that handle flammable and combustible liquids to implement the requirements of 1910.38 *Emergency Action Plans*.

2007-08-I-IL-R2

Amend 1910.38 *Emergency Action Plans* to require employers to conduct practice evacuation drills at least annually, but more frequently if necessary to ensure employees are prepared for emergencies.

.

The U.S. Chemical Safety and Hazard Investigation Board (CSB) is an independent Federal agency whose mission is to ensure the safety of workers, the public, and the environment by investigating and preventing chemical incidents. The CSB is a scientific investigative organization; it is not an enforcement or regulatory body. Established by the Clean Air Act Amendments of 1990, the CSB is responsible for determining the root and contributing causes of accidents, issuing safety recommendations, studying chemical safety issues, and evaluating the effectiveness of other government agencies involved in chemical safety.

No part of the conclusions, findings, or recommendations of the CSB relating to any chemical accident may be admitted as evidence or used in any action or suit for damages. See 42 U.S.C. § 7412(r)(6)(G). The CSB makes public its actions and decisions through investigation reports, summary reports, safety bulletins, safety recommendations, case studies, incident digests, special technical publications, and statistical reviews. More information about the CSB is available at www.csb.gov.

CSB publications can be downloaded at www.csb.gov or obtained by contacting:

U.S. Chemical Safety and Hazard
Investigation Board
Office of Congressional, Public, and Board Affairs
2175 K Street NW, Suite 400
Washington, DC 20037-1848

(202) 261-7600

CSB Investigation Reports are formal, detailed reports on significant chemical accidents and include key findings, root causes, and safety recommendations. CSB Hazard Investigations are broader studies of significant chemical hazards. CSB Safety Bulletins are short, general-interest publications that provide new or noteworthy information on preventing chemical accidents. CSB Case Studies are short reports on specific accidents and include a discussion of relevant prevention practices. All reports may contain safety recommendations when appropriate. CSB Investigation Digests are plain-language summaries of Investigation Reports.