

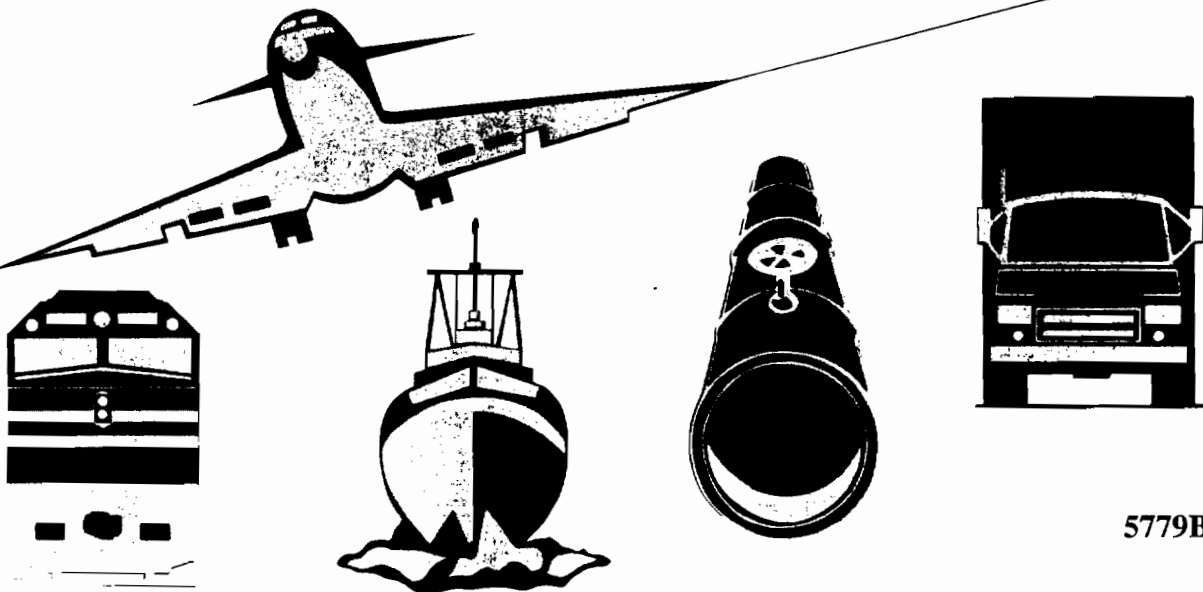
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NATIONAL TRANSPORTATION SAFETY BOARD

Washington, D.C. 20594

PIPELINE ACCIDENT REPORT

HIGHLY VOLATILE LIQUIDS RELEASE
FROM UNDERGROUND STORAGE CAVERN
AND EXPLOSION
MAPCO NATURAL GAS LIQUIDS, INC.
BRENHAM, TEXAS
APRIL 7, 1992



5779B

The National Transportation Safety Board is an independent Federal agency dedicated to promoting aviation, railroad, highway, marine, pipeline, and hazardous materials safety. Established in 1967, the agency is mandated by Congress through the Independent Safety Board Act of 1974 to investigate transportation accidents, determine the probable cause of accidents, issue safety recommendations, study transportation safety issues, and evaluate the safety effectiveness of government agencies involved in transportation. The Safety Board makes public its actions and decisions through accident reports, safety studies, special investigation reports, safety recommendations, and statistical reviews.

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NATIONAL TRANSPORTATION SAFETY BOARD

Washington, DC 20594

Pipeline Accident Report

HIGHLY VOLATILE LIQUIDS RELEASE FROM UNDERGROUND STORAGE CAVERN AND EXPLOSION MAPCO NATURAL GAS LIQUIDS, INC. BRENHAM, TEXAS APRIL 7, 1992

ADOPTED: NOVEMBER 4, 1993

NOTATION 5779B

Abstract: This report explains how highly volatile liquid products escaped from an underground storage cavern and formed a vapor cloud that exploded, killing three people and damaging almost all buildings within 3 square miles of the storage facility. From its investigation of this accident, the Safety Board identified safety issues in the following areas: safety control systems, cavern management procedures, employee and management performance, emergency preparedness, and Federal and State safety requirements and oversight for underground storage and related pipelines.

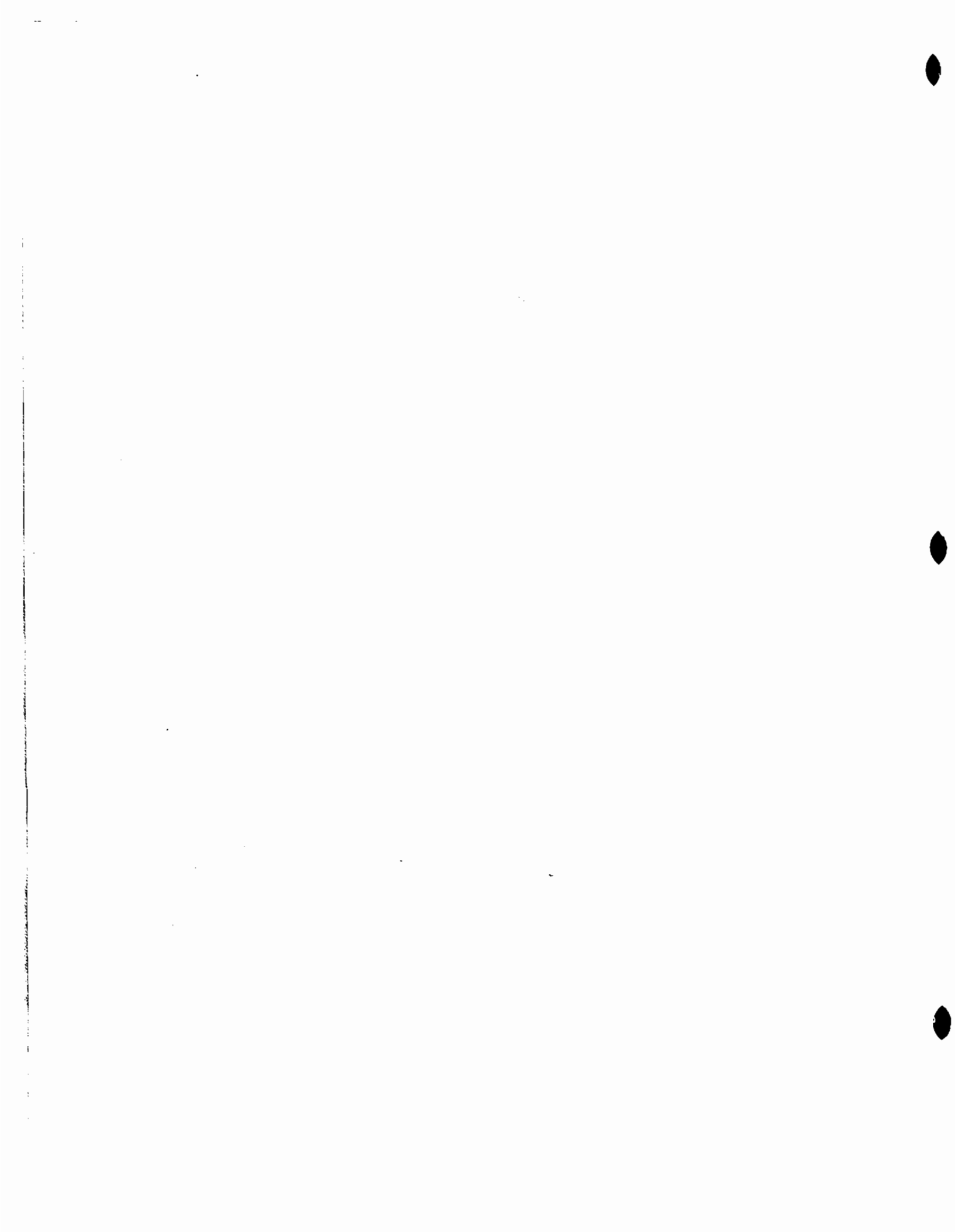
The National Transportation Safety Board made safety recommendations addressing these issues to the Department of Transportation, the Research and Special Programs Administration, MAPCO Natural Gas Liquids, Inc., the Texas Department of Public Safety, Washington County, the American Petroleum Institute, the American Gas Association, and the International Association of Fire Chiefs.

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EXECUTIVE SUMMARY

On April 7, 1992, an uncontrolled release of highly volatile liquids (HVLs)¹ from a salt dome storage cavern in the Seminole Pipeline System near Brenham, Texas, formed a large, heavier-than-air gas cloud that exploded. Three people died from injuries sustained either from the blast or in the fire. An additional 21 people were treated for injuries at area hospitals. Damage from the accident exceeded \$9 million.

The National Transportation Safety Board determines that the probable cause of the release of highly volatile liquid from the remotely operated and overfilled storage cavern and resulting explosion at Brenham station was the failure of MAPCO Natural Gas Liquids, Inc., (MAPCO) to incorporate fail-safe features in the station's wellhead safety system. The cause of the overfilling was the inadequacy of the company's procedures for managing cavern storage. Contributing to the accident was the lack of Federal and State regulations governing the design and operation of underground storage systems. Contributing to the severity of the accident was MAPCO's inadequate emergency response procedures.

From its investigation of this accident, the Safety Board identified safety issues in the following areas:

- o Safety control systems;
- o Cavern management procedures;
- o Employee and management performance;
- o Emergency preparedness;
- o Federal and State safety requirements and oversight for underground storage and related pipelines.

As a result of this investigation, the Safety Board issued recommendations to the Department of Transportation, the Research and Special Programs Administration, MAPCO Natural Gas Liquids, Inc., the State of Texas Department of Public Safety, Washington County, the American Petroleum Institute, the American Gas Association, and the International Association of Fire Chiefs.

¹ Highly volatile liquids are hazardous liquids that have a vapor pressure exceeding 40 psia (276 kPa) at 100° F (37.8° C) and that will form a vapor cloud when released to the atmosphere. The primary components in the HVL mixture in the Brenham storage dome were ethane and propane, which at 60° F and atmospheric pressure have a liquid to vapor expansion ratio of 300 and 270, respectively. (For further information, see "HVL Properties.")

**NATIONAL TRANSPORTATION SAFETY BOARD
Washington, DC 20594**

Pipeline Accident Report

**Highly Volatile Liquids Release from
Underground Storage Cavern and Explosion
MAPCO Natural Gas Liquids, Inc.
Brenham, Texas
April 7, 1992**

INVESTIGATION

The Accident

Events Before the Accident.--On April 7, 1992, the MAPCO² dispatch center in Tulsa, Oklahoma, was controlling the transport of highly volatile liquid (HVL) products from two south Texas processing plants through a section of the Seminole Pipeline Company's (Seminole's) system called the Bryan Lateral. From the lateral, the product was being injected into Seminole's salt dome storage cavern at the Brenham station near Brenham, Texas (see figure 1).

A dispatcher remotely controlled the Seminole pipeline system, including pump units that transported product through the Texas pipeline, from a telemetry system control console (see figure 2). At 6:09:39 a.m., the monitor screen began to flash an alarm indicating that one or more hazardous gas (HAZGAS) detectors had activated at Brenham station, which was an unattended facility. In accordance with company procedures, the dispatcher telephoned a technician at his home in the Brenham area, told him that the dispatch center had received a HAZGAS alarm from Brenham station, and requested that he check out the source of the alarm.

About 6:55 a.m., an Austin County resident, whose home on Glory Lane was adjacent to Brenham station, telephoned her mother, who lived on County Road (CR) 19, and told her that she smelled a "strong gas odor" outside her mobile home. The mother advised her daughter to call 911. At 6:59 a.m., when the mobile home owner dialed 911, the telephone system routed the call to the dispatcher for the Washington County Sheriff's Department (WCSD) in Brenham, Texas, about 8 miles away. According to the WCSD dispatcher, the caller sounded "woozy" when she told him that "...it smells like somebody has given a perm in my house." The caller

² MAPCO Natural Gas Liquids, Inc., currently has controlling interest in Seminole Pipeline Company, which is a stock corporation that has no employees. MAPCO Natural Gas Liquids, Inc., also wholly owns Mid-America Pipeline Company, which operates the dispatch center for all of its parent company's pipeline operations and which operates the Seminole system under contract. MAPCO Natural Gas Liquids, Inc., is a subsidiary division of the energy corporation MAPCO, Inc. Unless noted otherwise, the Safety Board uses the term "MAPCO" when referring to any company employee, operation, and procedure in the corporate tree. Additional information about the organization and ownership of companies involved in this accident appears later.

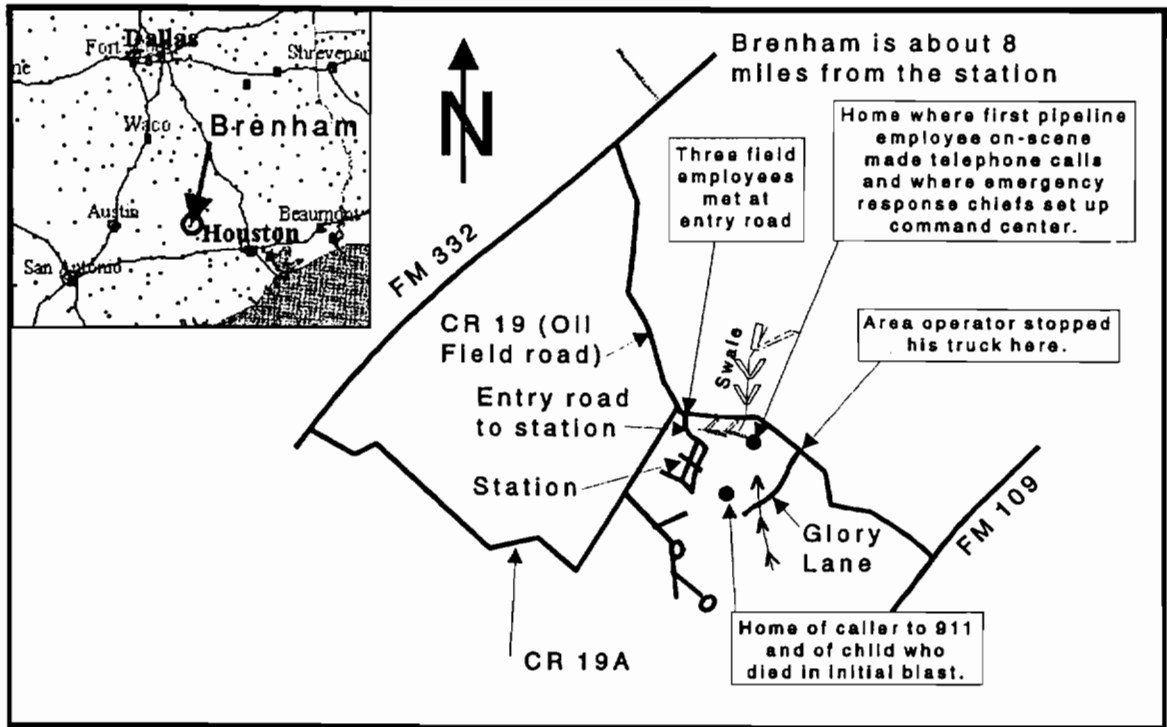


Figure 1. Map of accident area.

said "I don't know if something's happened over at the gas line ... I can hear something blowing out. It's never, never smelled like this. It's so strong."

The WCSD dispatcher transferred the caller to the Brenham Fire Department. While giving the fire department dispatcher directions to the Brenham station, the mobile home owner cautioned that CR 19 was "kinda foggy." In accordance with county procedures for a gas leak, the fire department dispatcher called MAPCO's dispatch center in Tulsa, and was advised that a technician in Brenham had already been alerted and was checking out the alarm.

The Explosion.--The mother of the mobile home owner stated that shortly after 7 a.m., she was driving her pickup northbound on CR 19 to pick up her daughter and grandson when she encountered another pickup stopped on the right side of the road, near the intersection of Glory Lane and CR 19. She said that when she started to pull around to the left side of the stopped pickup, a man blocked her.³ She said that when she told him that she needed to go down Glory Lane to help her daughter, the man told her that "there has been a gas leak...it [the gas leak] has been turned off" and "they were not allowing any vehicles down there."

The mother of the mobile home owner said that she had put her pickup in reverse in

³ A MAPCO area operator had stopped his truck south of the intersection.

order to back up toward her driveway when she saw a car approaching CR 19 from the Glory Lane area. She said that when the car from Glory Lane reached CR 19, the woman driving glanced at the two pickups to her right, turned left, and proceeded north toward the cloudy swale.⁴ The woman driving the pickup truck said that the man who had stopped her shouted at the car to stop, but the car driver failed to do so.

Three pipeline employees were near the station entry road on the opposite side of the fog-filled swale. One testified that he saw the headlights of the northbound car. He later testified that he believed that the vehicle was that of a pipeline employee, the assistant maintenance supervisor. When the motorist continued to drive into the vapor cloud, he realized his mistake and tried to get the car driver to stop by yelling and waving.

According to descriptions of two employees, the oncoming car "disappeared" into the vapor-fog cloud. One man said that he next heard the sound of someone attempting to start a car. Another stated that a flash occurred where the vehicle had entered the vapor cloud. He said the flash "occurred over a great deal of land...up and toward the station and out [and] down the ravine [swale]."

The Brenham fire department dispatcher said that when he called the mobile home owner back to notify her that the pipeline company was checking out the gas alarm, "there was a tremendous boom and the phonelines went dead." At 7:13:57 a.m., the Tulsa telemetry system ceased receiving data transmission from Brenham station.

Two other employees who were en route to the site from different directions described the ignition of the gas cloud and resulting explosions. An assistant maintenance supervisor was driving north on CR 19 from Farm to Market (FM) 109 when he observed a large "fireball" reflecting off the clouds and three rapid flashes of light that jumped around like lightning. He felt three concussions immediately thereafter that violently shook his truck.

A lab technician stated that he was driving on FM 332 when he observed a large

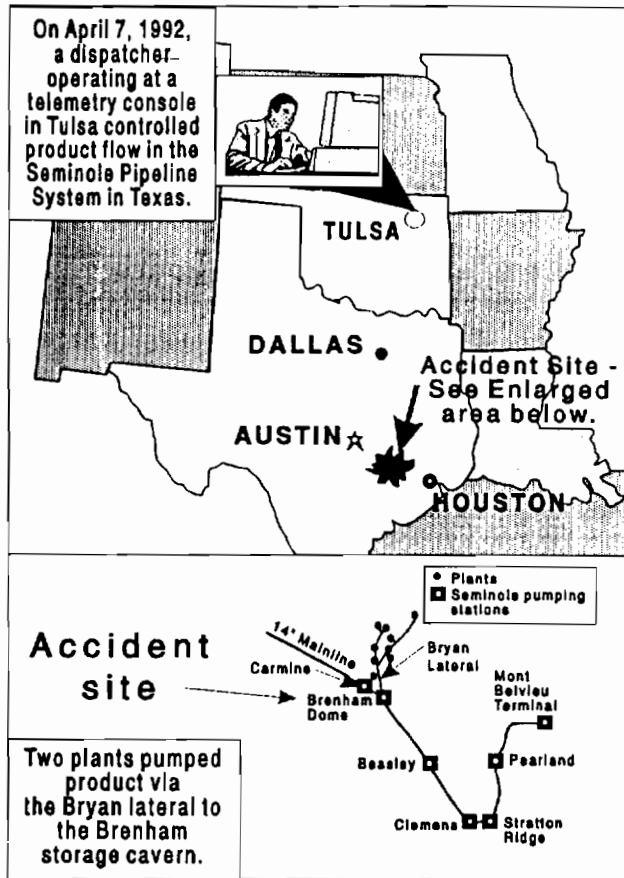


Figure 2. Employee at Tulsa dispatch center controls HVL transport in the Bryan Lateral.

⁴ A low-lying stretch of land.

mushroom-shaped cloud covering the station area and several smaller clouds east of the site. He said that he was about 2 1/2 to 3 air miles from the station when "the [gas] cloud exploded as in a fire and turned orange. There was a series of explosions [that] sounded like thunder." He said that three or four "secondary explosions" occurred as smaller clouds, which had "detached from the larger cloud," exploded. The lab technician described the explosions as being "somewhat like a lightning storm."

The surface blast demolished all buildings at the Brenham station and caused varying degrees of damage to all homes within a 3-square-mile area. Seismological recordings at three Texas universities within 75 air miles of Brenham station showed that the surface tremor, which rattled the windows of homes more than 130 miles away, registered 3.5 to 4 on the Richter scale.⁵ A young boy in the mobile home adjacent to Brenham station was killed when his parent's home was leveled by the force of the explosion. The car that entered the vapor cloud had three occupants, two adult women and a child, all of whom were seriously burned in the accident and MEDEVACed to Hermann Hospital Burn Center in Houston, Texas, where the two adults died later in the week. An additional 21 people were treated for blunt force trauma, lacerations, and burn injuries at area hospitals.

Emergency Actions

Before the Explosion.--The technician in Brenham testified that upon being notified of the gas alarm by the Tulsa dispatch center, he dressed and began the drive to the storage cavern, during which he stopped at a convenience store for a soft drink. He said that about 6:45 a.m., he was proceeding northwest on CR 19 near Brenham station when he smelled gas product and observed "a very thick mixture of gas and fog." He stopped his truck a short distance before the swale and turned the ignition switch off. He said that when the pickup continued to run, "I knew something serious had happened" because "there was enough gas in the air to keep feeding my engine." He did not have a self-contained breathing apparatus in his truck.

The technician stated that he was apprehensive about using the two-way radio in his company truck for fear of igniting the HVL vapor, so he left his truck, went to the nearest home, and asked to use the owner's phone. He called the Tulsa dispatcher, advised him that gas was in the area, and asked him to notify his (the technician's) immediate supervisor. He did not ask the dispatcher to contact other area employees that he knew should soon be reporting to the station to begin their workday. The technician left, but according to the homeowner, he returned less than a minute later and asked for a telephone book so that he could call his supervisor himself. The Assistant Maintenance Supervisor later testified that when the technician advised

⁵ A logarithmic scale for expressing the magnitude of a seismic disturbance in terms of the energy dissipated in it. A reading of 2 indicates the smallest earthquake that can be felt, 4.5 indicates an earthquake causing moderate damage, and 8.5, an earthquake causing devastating damage. For example, the 1989 San Francisco Bay quake registered 6.9 on the Richter scale.

him that the leak was getting larger and that "gas was crossing CR 19," he instructed the technician to block the road and not enter the vapor cloud.

After he hung up, the technician told the residents that he was going to block the road and that they should shut off any electrical appliance they were operating, not operate any other appliance, and evacuate the area on foot toward FM 109. When one of the residents told him that a schoolbus was soon scheduled to come down CR 19 from the north, he rushed out of house and toward the station, not stopping to block the road. He covered his mouth and ran down CR 19, through the vapor-cloud fog in the swale, and up toward the station entry road.

A pipeliner and technician trainee, who were riding together in a company truck to the station, saw the vapor fog cloud as they turned off FM 332 onto CR 19 and approached the worksite from the northwest. About 7 a.m., they turned onto the station entry road and stopped their pickup about 200 yards from the station gate. When they rolled down the truck's windows, they smelled product and could hear a "roaring noise."

The pipeliner instructed the technician trainee to use the truck radio to determine who was in the area. While the trainee was calling on the radio, the pipeliner walked toward the station gate. About 100 feet from the gate, he saw that it was locked, which indicated to him that no one was at the station, so he stopped. He then saw a column of "water ... about 12 inches in diameter ... shooting about 50 feet into the air..." He believed the column was coming "...out of the brine line⁶ in the corner of brine pond No. 1" and immediately returned to his truck.

The technician trainee was using the radio when the pipeliner returned to the truck. While the pipeliner got the truck keys to retrieve a portable gas detector from the vehicle, the trainee walked toward the direction of a noise "like a fountain ... bubbling water, spraying, and a hissing" When he got to the culvert in the entry road, he saw "fluid gushing up." As he walked closer to the station gate, he noted that the vapor was up to the level of his ears. He then returned to the truck and radioed the area operator to tell him of his observations. The area operator advised him that the two of them should leave the area.

The pipeliner and technician trainee next saw the technician running up the road toward them. After briefly discussing what actions they should take, one employee started walking toward the intersection of CR 19 and CR 19A to block traffic, another started walking south on CR 19 to block traffic on the other side of the swale, and the third started toward the station.

Meanwhile the area operator had turned onto CR 19 from FM 109. As soon as he saw

⁶ The brine tube, also referred to as the "brine line," contained salt water that, because of its greater specific gravity, contained the HVL product within the underground storage facility. Additional information about the underground storage facility will appear later in this report.

the fog/product in the swale, he got out of his truck and started to walk toward the station. He stopped before reaching the fog, looked toward the station, and saw "a water column shooting up." He returned to his truck and radioed the Tulsa dispatcher to shut down the gathering system. The area operator next tried unsuccessfully to radio his supervisor. He then used his mobile telephone to call the lab technician. The area operator described his observations and told the lab technician that he believed that HVLs were being released from the cavern. The area operator testified that he had finished talking with the lab technician when a pickup truck driver drove up and told him that she needed to pick up her daughter from a house down the gravel road to his left (Glory Lane). He said that he looked down Glory Lane, "saw clouds" in the area, and advised her that she could walk down to get her daughter but that she could not drive into the area. As the area operator was watching the pickup driver, another motorist exited Glory Lane and drove her car into the vapor cloud. Seconds later the explosions occurred.

Postexplosion

Actions by Area Employees.--The assistant supervisor approached the station via CR 19 from FM 109, stopping his vehicle just south of the swale. He said that because he was concerned about the potential for another explosion and because the residents that he passed appeared to be functioning satisfactorily, he went directly to the station, advising people whom he passed that ambulances were on the way. When the assistant supervisor entered the station gate, he was aware of fires in the station, but did not see any area where HVL vapors were being released or accumulating.

While en route via CR 19 from FM 332 to the station, the lab technician said that he stopped briefly whenever he observed residents near the road who looked as if they needed assistance and radioed the Tulsa dispatcher of the need for ambulances. When he first arrived at the station, he assisted two employees who had sustained minor injuries when the surface blast knocked them to the ground. When the lab technician initially glanced around the station, he noted fires burning at the following station and perimeter locations: the tool house, the hay barn, the transformers at the control building, an oil tank on the west side of the station, Coastline Gas Pipeline Company's (Coastline's)⁷ above-ground piping, and the Seminole truck on the station entry road outside the compound.

While other employees tended to injured residents and established area roadblocks, the assistant maintenance supervisor, the lab technician, and the technician checked and closed valves within the station. The assistant maintenance supervisor walked over between the two brine ponds to close the 14-inch mainline valve. The lab technician checked the condition of the station piping and found that the only HVLs being released were coming from control equipment. He noted a leak from a valve stem at one piece of control equipment and one on

⁷ Coastline Gas Pipeline Company is a wholly-owned subsidiary of MidCon Texas Pipeline Corporation (formerly United Texas Transmission). Coastline owns a 6-inch-diameter HVL pipeline that originates in Colorado County, Texas, and extends approximately 45 miles to its terminus at Seminole's Brenham station.

meter piping. While walking through the station, the lab technician noticed that the cavern safety valve at the wellhead was tripped. He did not recall seeing any water or vapor being released near the wellhead or observing the position of any other equipment there. After closing and chaining closed various valves throughout the station, the lab technician reached the meter run for Coastline's pipeline, where he noted that both manual valves between the Seminole and Coastline pipelines were closed.

The assistant maintenance supervisor and the lab technician divided the station area to do a cursory check for damage to pipeline system components and to secure the site. In the course of his damage check, the lab technician walked up to the top of the berm surrounding pond No. 1 and noted a fire above the brine in the middle of the pond.

The assistant maintenance supervisor and other employees went to the wellhead. In a pile of debris near the wellhead, they found a component of the cavern safety valve system,⁸ the Barksdale pressure switch, had broken from its mounting and separated from the electrical signal wire in the system. The assistant maintenance supervisor saw that another cavern safety valve system component, the brine pressure sensing tubing, was dangling down into the debris. He did not determine whether the sensing tubing was still connected to the Barksdale switch. He later testified that although he could not recall any water or vapor being released from the tubing, he believed that he reached up and closed the valve between the brine tube and the sensing tubing. When he returned to the wellhead after checking other station sites, the assistant maintenance supervisor noted that the valve from the brine tube to the brine pressure sensing tubing was closed and that the tubing was not attached to the Barksdale switch. When an employee who was with him opened the closed valve, HVL vapors escaped from the open end of the sensing tubing.

About 10:30 a.m., the lab technician returned to the wellhead. He also found that the valve from the brine tube to the brine pressure sensing tubing was closed, but that the sensing tubing was missing. He later testified that at the time, he believed the tubing had been blown away by the explosion.

Community Agencies' Actions (See figure 3 for a summary of the community response effort).--The Washington County Emergency Management Coordinator (EMC)/Emergency Medical Services (EMS) Director stated that he was getting out of bed when he heard a rumble and a loud explosion that rattled his brick home and its windows. As he left his house, which was several miles north of Brenham, he saw a large pink cloud rising to the south. When he got into his car, he overheard radio traffic say, "It's the salt dome." He testified that he immediately called the EMS dispatcher and told her to activate the Washington County Disaster Plan. As he proceeded to the scene, he called his dispatcher again to request that all available medical

⁸ The wellhead had a cavern safety valve system. When closed, the cavern safety valve prevented the flow of HVLs from the cavern to the brine ponds. The various components of the system were designed to trigger the closure of the cavern valve should excessive pressure or heat be detected. An illustration of the cavern safety valve system appears later in this report.

evacuation helicopters be dispatched from Houston and Austin. He also called Trinity Medical Center and activated the hospital's disaster plan. When he arrived on scene, the EMC/EMS Director had to radio backup personnel to tell them to reroute because debris from fallen trees and disabled vehicles blocked CR 19.

The chief of the Brenham Fire Department was also at home when the explosion occurred. When he reached his vehicle, he received a radio call from the sheriff's department advising him of an explosion at the salt dome in southwest Washington County. He radioed for a fire alarm and proceeded to the station site via FM 109 to CR 19, which he found blocked by fallen trees and a charred car. He then had to radio fire fighting personnel to reroute to the station by way of FM 332 to CR 19. The fire chief stated that he made his way on foot, climbing through debris, up to Brenham station, where he talked to the pipeline employees and determined that none of the fires at the site posed an immediate life-threatening situation.

Fire Departments.--Four departments with a total of 7 pieces of fire fighting apparatus and over 100 firefighters

Law Enforcement Agencies.--Between 45 and 50 enforcement personnel representing 18 enforcement agencies

EMS.--Two county EMS departments with 39 personnel

Other.--Three medical evacuation helicopters from Houston.

Figure 3. Number of community responders to Brenham accident.

After observing the extent of injuries to area victims, the EMC/EMS director, the fire chief, and the chief deputy of the sheriff's department decided to set up the command post at the driveway of the residence closest to the Brenham station and to establish two triage areas on CR 19, one north of the station, near the intersection of CR 19 and CR 19A, and one south of the station, near the intersection of CR 19 and FM 109. The first patients evacuated arrived at Trinity Medical Center in Brenham at 7:45 a.m. The car's three occupants were initially taken to Trinity, from which they were MEDEVACed by LIFE-FLIGHT to the burn center at Hermann Hospital in Houston.

Documented Injuries.--Table 1 on the following page categorizes injuries sustained in the Brenham accident according to the International Civil Aviation Organization's method of injury coding as described in 49 *Code of Federal Regulations* (CFR) 830.2. The injury table does not include individuals who sought private medical treatment.

Station Damage.--Safety Board investigators found that the surface blast leveled all of the buildings and most of the fencing at the Brenham station, damaged the brine pond liners, shifted an above-ground storage tank on its concrete base, and knocked down the power lines. The station piping sustained minor damage. MAPCO estimated the cost of rebuilding the station to be \$3,400,000. The company did not provide a cost estimate for business losses resulting from the station being out of service since April 7, 1992.

Other Damage.--More than 60 homes in Washington and Austin Counties were damaged. Of the damaged residences, 26 buildings within 1 1/2 miles of the station were declared a total loss and 33 residences within 1 1/2 to 2 miles of the station sustained moderate damage (see

figure 4). The blast also killed 75 beef cattle and injured dozens more. Estimates of damage to area homes and structures exceeded \$5 million.

INJURIES	PIPELINE EMPLOYEES	RESIDENTS	OTHERS	TOTAL
Fatal	0	3	0	3
Serious	0	2	0	2
Minor	2	17	0	19
TOTAL	2	22	0	24

Table 1. Injuries sustained in Brenham pipeline accident.

System Organization/Ownership

MAPCO, Inc., an energy company that is diversified through subsidiaries and affiliates, produces coal and natural gas liquids; refines and processes crude oil; transports natural gas liquids, refined petroleum products, and anhydrous ammonia by pipeline; markets and trades natural gas liquids, refined petroleum products, coal, fertilizers, and domestic and foreign crude oil; and markets convenience-store merchandise. Incorporated in Delaware in 1958, MAPCO, Inc., has executive offices in Tulsa, Oklahoma. It has three subsidiary divisions: MAPCO Natural Gas Liquids, Inc.,⁹ MAPCO Coal, Inc., and MAPCO Petroleum, Inc. MAPCO Natural Gas Liquids, Inc., owns and/or directs all pipeline operations for MAPCO, Inc.

In September 1980, the corporation now known as Seminole Pipeline Company was formed to complete a project to construct, maintain, and operate a 14-inch pipeline for the transportation of natural gas liquids in Texas. When it was founded, Seminole was a partnership of subsidiary companies whose ultimate parent companies were MAPCO, Inc., Enterprise Products Company, Standard Oil Company of Indiana (now Amoco Corporation), and Getty Oil Company (now Texaco, Inc.). The Seminole system includes nearly 1,300 miles of pipeline, extending from Hobbs station in west Texas to the Mont Belvieu terminal on the Texas Gulf Coast.

In addition to the Brenham salt dome cavern, the Seminole system includes two other salt dome caverns and one bedded salt cavern. MAPCO Natural Gas Liquids, Inc., has no salt dome caverns but owns 75 mined or washed underground storage caverns in Texas, Oklahoma, Kansas, Nebraska, Iowa, and Illinois. All of these caverns are connected to the Mid-America's system of nearly 7,000 miles of pipeline.

⁹ At the time of the accident, the subsidiary of MAPCO, Inc., that had controlling stock interest in Seminole Pipeline Company was MAPCO Transportation, Inc. In January 1993, MAPCO, Inc., merged the pipeline-related operations of all its subsidiaries under MAPCO Natural Gas Liquids, Inc.



(Above) This home was about 1/2 mile from Brenham station.

(Left) Site of mobilehome from which owner called 911 at 6:59 a.m.

(Below) Technician who was first on scene placed calls to his supervisor and the dispatch center from this home.

Photos courtesy of The Brenham Banner-Press



Figure 4. Area residences damaged by blasts.

Facilities

Brenham Station.--The station is on a 51.35-acre site that straddles the Washington-Austin County line. According to a company representative, Brenham station's primary function is to transport HVLs for consignees along the Seminole pipeline. Brenham station also serves as an accumulation and delivery point. The site receives and accumulates HVLs from processing plants along the Bryan Lateral and from the Coastline pipeline; the site delivers HVLs to Seminole's 14-inch mainline and to Coastline's pipeline.

HVLs at the station are stored in a solution-mined cavern that is more than 1/2 mile below the surface in the Brenham salt dome (see figure 5). Because the Tulsa dispatch center could operate by remote control the pumps and valves needed to route HVLs at Brenham station, the facility was not staffed 24 hours per day. Field personnel assigned to the area went to the station each day to perform required readings, maintenance, and other duties. (Information about employees' specific job duties appears later in this report.)

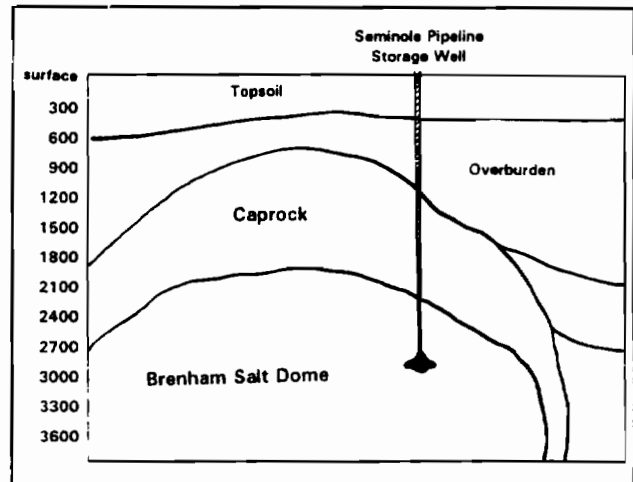


Figure 5. MAPCO geologist's drawing of the storage cavern within the Brenham salt dome.

Background of Cavern.--In July 1981, MAPCO applied to the Texas Railroad Commission (TRC), for a permit to "leach" a 150,000-barrel capacity cavern. The company constructed the underground cavern by drilling a well through the overburden and caprock and into the salt formation. In the well hole, the company installed 2,702 feet of 13 3/8-inch-diameter pipe, which was cemented in place. Inside the 13 3/8-inch pipe, the company installed an 8 5/8-inch-diameter pipe to a depth of 2,879 feet below the surface. The pipes initially served as channels through which the company pumped fresh water down to the salt strata. The injection process caused the water to circulate within the salt formation and dissolve the salt, forming a cavity that contained salt water solution, or brine. The company then pumped out the brine and stored it in an elevated brine pond at the surface. The bermed pond was lined with plastic to keep the brine that was removed from being absorbed into the ground.

The company continued injecting fresh water and removing brine solution until a cavern large enough to begin storage operations was formed (about 20,000 barrels). The 8 5/8-inch-diameter pipe served as a flow line for brine between the cavern and the surface. The annulus, or space, between the two pipes was the flow area through which liquid product could flow into or from the cavern.

Product Storage.--MAPCO added and removed HVLs to and from the Brenham station cavern by means of brine displacement (see figure 6). Brine filled the bottom of the cavern; HVL product filled the upper area of the cavern. Because the specific gravity of brine is more than twice that of HVLs, the weight of the brine in the brine tube contained the HVLs in the cavern. To add product into the cavern, the product pressure was increased by pumping. As product pressure became greater than the pressure produced by the weight of brine at the bottom of the brine tube, the brine level in the cavern was pushed lower and brine was pushed up the brine tube and into two brine ponds at the surface. Conversely, when product was removed from the cavern, the resulting drop in product pressure allowed the heavier brine to flow back down into the cavern from the surface ponds.

Brine Ponds.--Pond No. 2, which has a capacity of 150,000 barrels, is immediately adjacent to the wellhead (see figure 7). Pond No. 1, which has a capacity of 100,000 barrels, is northeast of and next to Pond No. 2. The two brine ponds are connected by a 12-inch-diameter pipeline, which also connects to the 8 5/8-inch brine tube near the wellhead. The 12-inch line is used to transfer brine to and from the cavern and to help keep the surface levels of the two ponds even. If the amount of brine is insufficient to displace HVLs from the cavern, the brine system has two pumps that can be used to inject fresh water into the brine tube.

Cavern Growth.--In a salt dome facility, whenever the brine is less than fully saturated, salt dissolves from the cavern walls, thereby gradually increasing the size of the cavern. The salinity of the brine can be reduced as a consequence of weather, such as when rainwater mixes with the brine in the ponds at the surface, or when an operator draws off some of the brine and replaces it with fresh water. Records show that MAPCO periodically sold brine to drillers. As a result of periodic dilution from rain and from partial substitution of fresh water for brine by the company, the volume of Brenham cavern had grown from about 20,000 barrels when operations began in September 1981 to about 336,000 barrels in May 1991 (see figure 8).

To determine the increase in cavern size, the company periodically contracted sonar measurements of the facility. In his research paper, "Instrumentation and Controls for Solution-Mined Underground Storage Systems," Neal E. Van Fossen describes the operation of the sonar caliper and states that the "order of accuracy" for the procedure is generally plus or minus 5 percent.¹⁰ Other industry representatives have characterized the order of accuracy as 10 percent or greater. A spokesperson stated that MAPCO recognized that sonars were not precise and could not be used to determine the volume of a specific interval within the cavern. The spokesperson also stated that once the company determined the cavern's capacity, as an operating safeguard, it based product storage on a working capacity that was 10 percent below total capacity.

¹⁰ From the *Fifth Symposium on Salt -- Volume Two*, The Northern Ohio Geological Society, Inc. (1988).

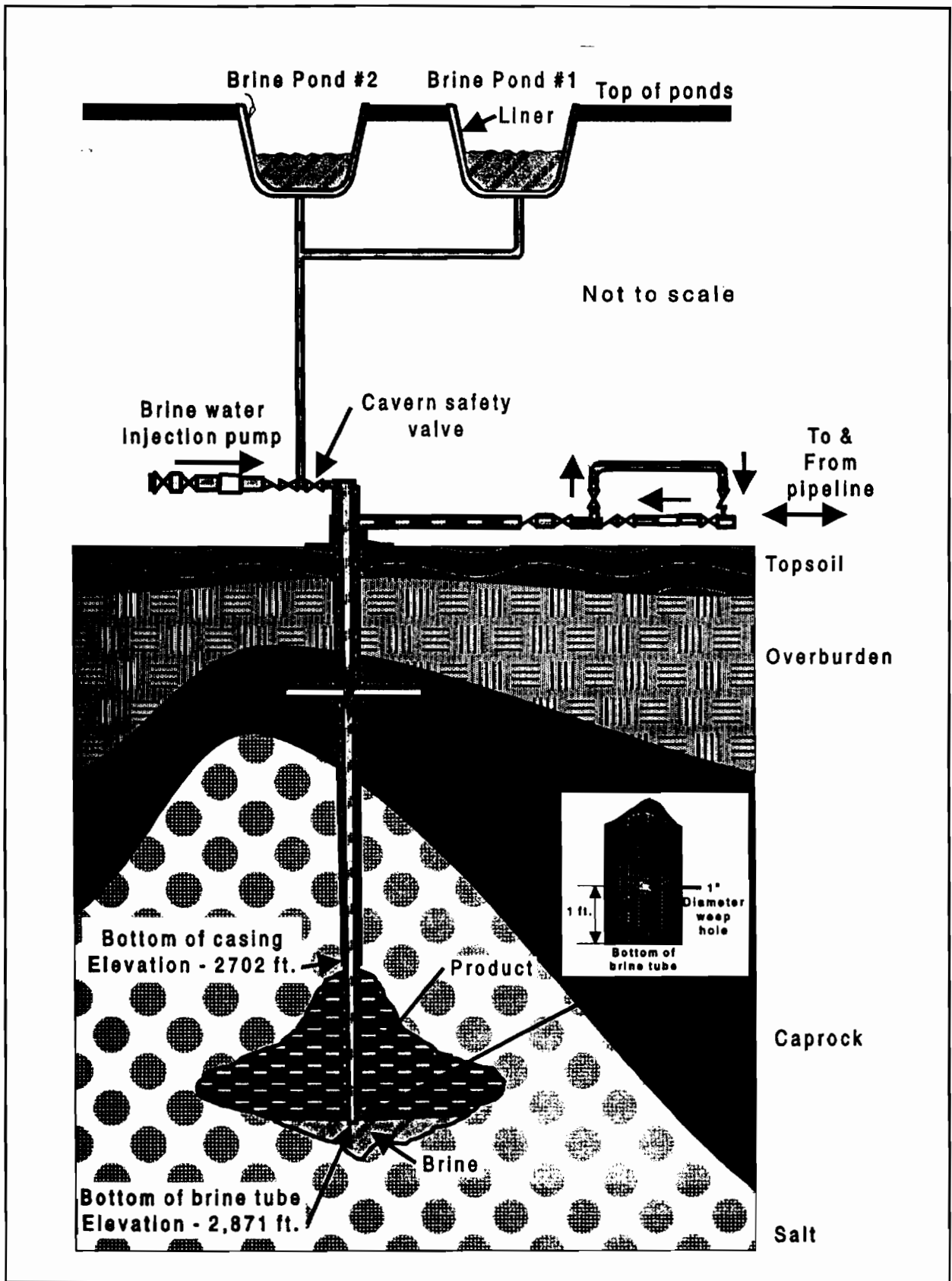


Figure 6. Cavern storage facility.

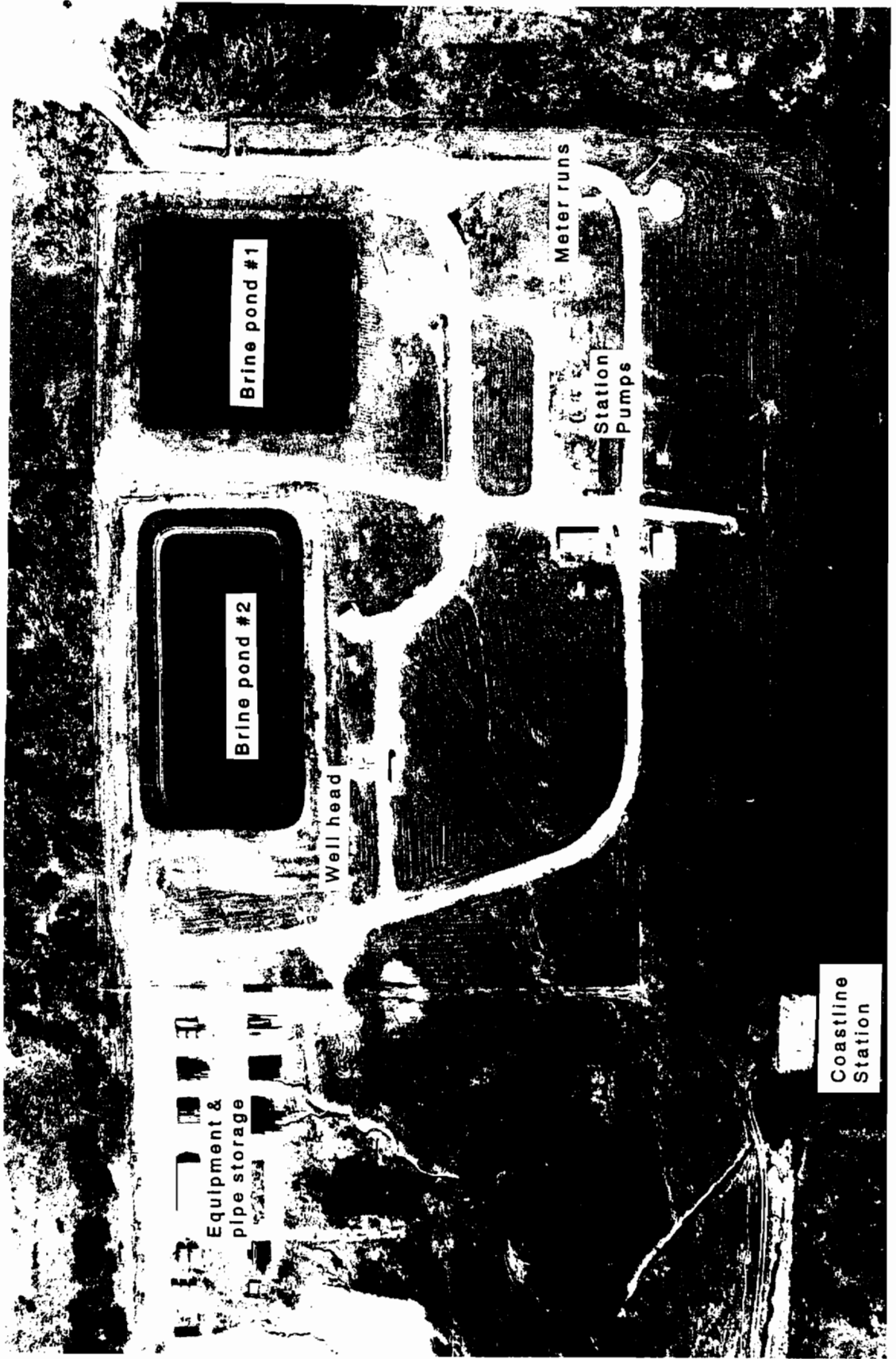


Figure 7. Overhead of station showing brine ponds.

Jul 1981	MAPCO files for authority to construct a cavern with a proposed capacity of 150,000 barrels.*
Sep 1981	MAPCO begins operating cavern with an initial volume of 20,000 barrels.
Nov 1982	Cavern volume tests indicate capacity is 65,938 barrels.
Oct 1986	Cavern volume tests indicate capacity is 111,000 barrels.
Nov 1987	Calculations indicate cavern capacity is about 154,000 barrels. MAPCO establishes the cavern working capacity at 130,000 barrels.
Mar 1988	After a February 1988 HVL release from Brenham cavern, MAPCO contracts a sonar measurement of the cavern from which volume was calculated to be 173,000 barrels. MAPCO sets cavern working capacity at 165,000 barrels.
May 1991	Based on sonar tests of the cavern, MAPCO calculates capacity to be 336,580 barrels and increases working capacity to 300,000 barrels.

*Although MAPCO's application was for a 150,000-barrel cavern, the Texas Railroad Commission order authorizing construction of the cavern did not include a capacity limitation.

Figure 8. Expansion of Brenham cavern.

Station Piping and Valves.--Three pipelines provided the primary means of product transport to and from Brenham station (see figure 9). The Bryan Lateral, an 8-inch pipeline spanning 41 miles, transported HVLs from several processing plants northeast of the station; a 6-inch line transported HVLs to and from Coastline's pipeline system at the southwest side of the station complex; and a 6-inch line transported HVLs to Seminole's 14-inch mainline.

Within the station piping system, the principal piping for transporting product was a 6-inch-diameter line that could take HVLs from the Bryan Lateral to Seminole's 14-inch-diameter mainline, to Coastline's 6-inch-diameter pipeline, or to the cavern piping and an 8-inch-diameter line that could move product to and from the cavern. Through valve, piping, and control equipment arrangements, only MAPCO could control the flow of HVLs in or out of Brenham. The motor-operated valves could be opened and closed either by a dispatcher in Tulsa or by on-site personnel at Brenham station. A control valve at the cavern pump regulated the pump suction pressure to maintain a pressure of 450 psig or more.

Coastline's Riser.--Coastline's 6-inch pipe connected to the Seminole system at the southwest boundary of the station. The pipe exited and re-entered the ground in an area enclosed by chain-link fence.

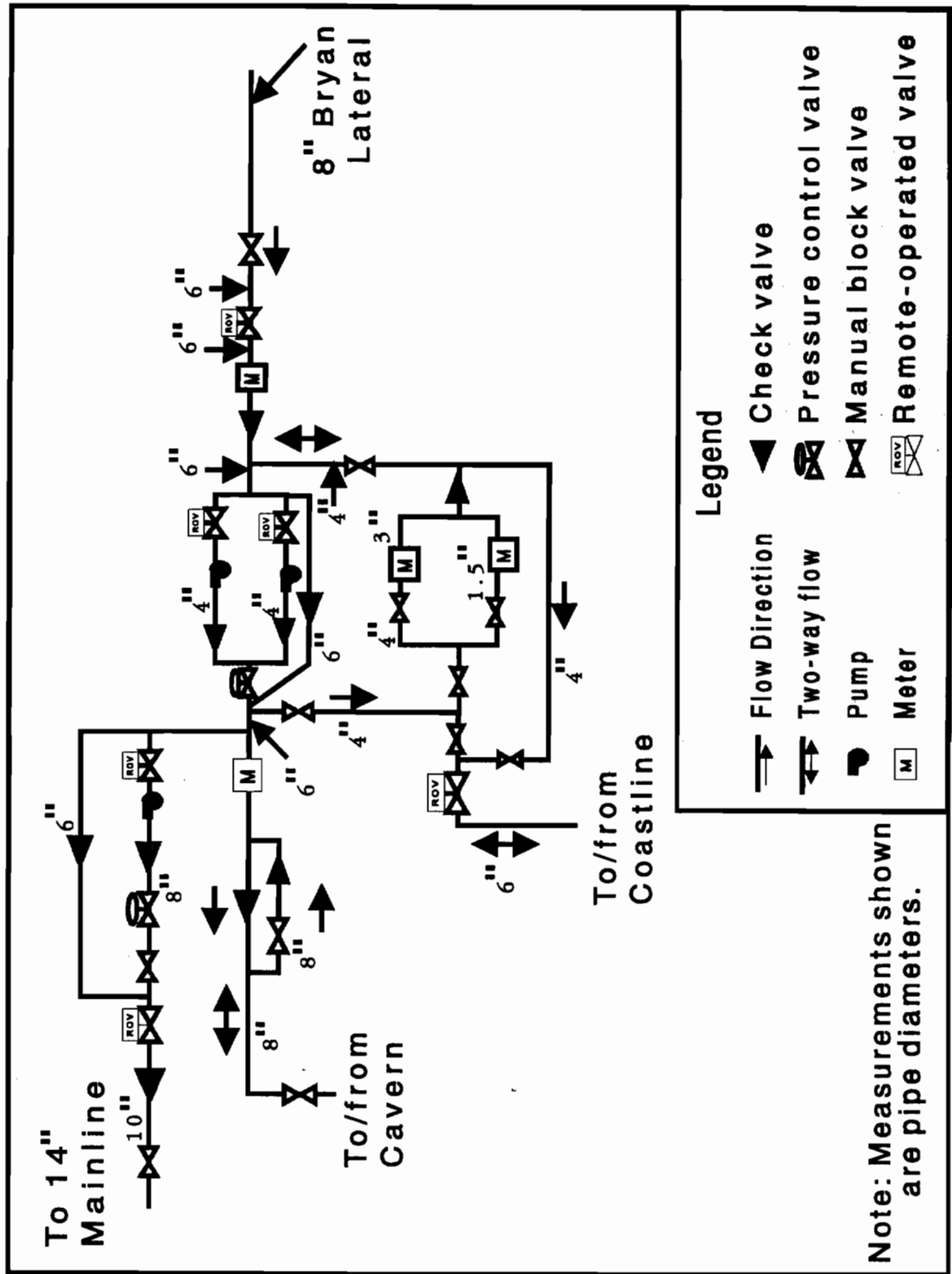
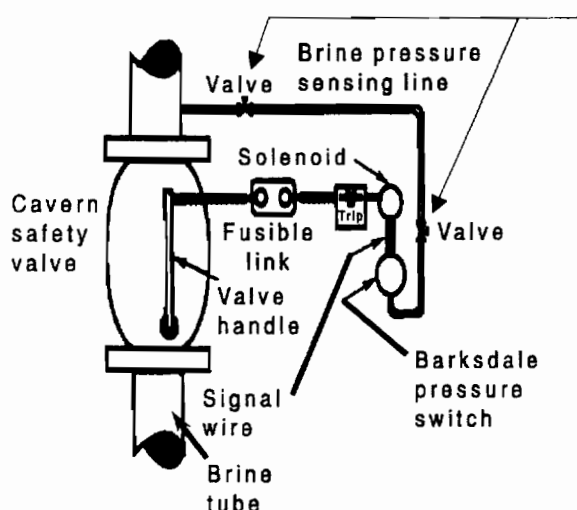
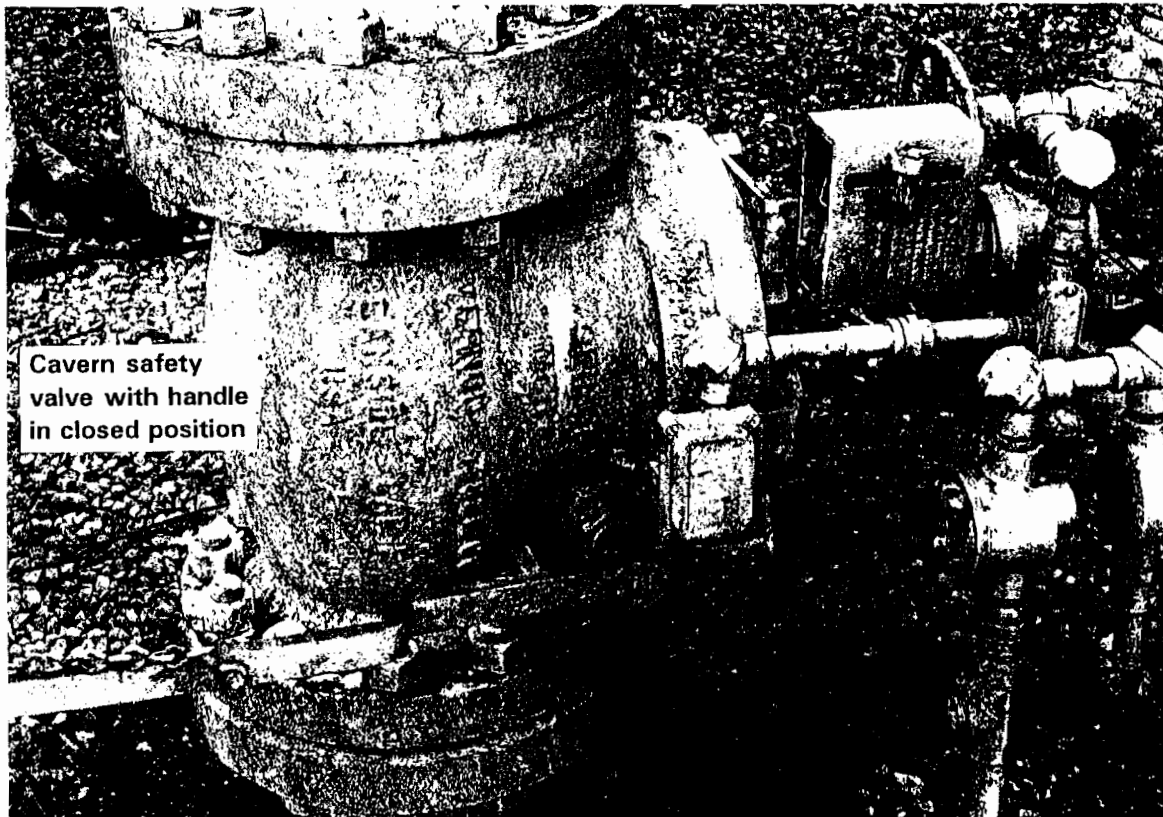


Figure 9. Schematic of Brenham station piping system.

Cavern Safety System (See figure 10).--When the Brenham station was constructed, no industry or government standards existed that described the type or design of equipment needed to provide a specified level of safety control. An executive officer and former chief engineer for

In the closed position, the cavern safety valve prevents HVLs from flowing from the cavern to the brine ponds. The manufacturer's literature advised that valve operation could be controlled by a fusible link, a manual cable, or a pneumatic or solenoid actuator.



For the system to function correctly, both manual valves in the brine pressure sensing line must be open.

A chain containing a fusible link (165° F) holds the spring-loaded cavern safety valve in the open position. The chain is connected to a lever on an electrically operated valve.

If the fusible link separates as a result of a fire or other heat source that increases the temperature of the link to 165° F or more, the cavern safety valve closes.

A Barksdale switch initiates movement of the cavern safety valve by sending an electrical signal to the solenoid lever to release the chain when the Barksdale switch detects a pressure of 100 psig in the brine tube.

Figure 10. Components of the cavern safety valve system.

the company said that MAPCO engineers designed the station, including the configuration of the station's cavern safety system and selected equipment, after reviewing the practices of other companies that were operating caverns at the time. He characterized Brenham's cavern safety system as "state of the art at the time it was installed and now" and added that other Seminole cavern storage facilities had comparable safety systems.

Near the wellhead, the company had installed equipment that was to automatically shut down the station pumps should the gas detectors sense a significant level of HVL in air. If excessive pressure built up in the brine tube or excessive heat built up near the wellhead, the cavern safety valve¹¹ in the brine tube was to close, thereby preventing HVLs from exiting the cavern through the brine ponds.

About 1 foot up from the base of the brine tube was a 1-inch-diameter weep hole. According to an executive officer of the company, the weep hole was installed to provide a "warning" that the product level was approaching the base of the brine tube and that the cavern was being overfilled. He explained that when the HVL level reaches the weep hole, product begins to enter slowly into the brine tube because the pressure differential across the weep hole is small. Product entering the brine tube through the weep hole then rises to the brine pond, where it escapes into the atmosphere as a vapor and triggers a gas detector that transmits an alarm signal to the Tulsa dispatch office. A small vapor release would also serve as a visual indicator to personnel who happen to be at the unmanned station that the cavern was becoming overfilled. They could then close the cavern valve manually.

The officer added that it is possible that while the HVL level is approaching the base of the brine pipe, enough product might enter the weep hole to sufficiently increase the pressure in the brine tube to activate the cavern shutdown system before the product reached the bottom of the brine tube.

Hazardous Gas Detectors.--Detectors were installed around the brine ponds and at other station locations to alert employees who might be at the station and the dispatch center of an HVL release within the station. Brenham station had 20 hazardous gas detectors: 8 spaced around each brine pond, 1 at the wellhead, 1 near the cavern injection pumps, 1 at the mainline injection pump, and 1 at the building housing station control equipment.

Detectors operated by pulling in nearby air and passing the air sample across a catalytic sensor. If the air sample contained hydrocarbons, the electrical circuit within the sensor oxidized the hydrocarbons, which caused a temperature increase in the circuit. The resulting increase in electrical resistance was transmitted as an electrical signal to a monitor in the control building, where the signal registered as a gas-in-air percentage of the lower explosion limit (LEL).

¹¹ Also known as the trip check valve or emergency shutdown device.

In the control building, indicator lights lit up when a gas detector had been activated. When a yellow indicator light lit up, the detected gas-in-air concentration was at least 25 percent of the LEL. Illumination of a red indicator light meant that the detected gas-in-air concentration exceeded 38 percent of the LEL. At the 38 percent level, all pumps at the station automatically shut down, and a single signal was transmitted to the dispatch center, where it was displayed as a safety fault on the dispatcher's monitor screen and on the alarm screen and printed out on the alarm logger.

Regardless of whether one detector or several detectors at the Brenham station sensed gas and activated, the Tulsa dispatch center received only one signal. The dispatcher controlling the Seminole system did not have the capability to determine the location or magnitude of any gas release or the means to differentiate whether an alarm signal had been caused by an actual HVL release or some other cause. Company maintenance records showed that other factors also caused a gas alarm to activate, even when gas vapors were not present, including detector failure, excessive brine moisture in the detector, nearby lightning, and degeneration of electrical components in the detectors. To determine whether an actual emergency existed, MAPCO procedures required that the Tulsa dispatcher contact an area technician, who was to immediately check out the site to determine why an alarm had been transmitted from the station.

During the 8 years before April 7, 1992, less than 10 percent of all detector alarms received from Brenham were the result of HVL releases at the station; none of the releases detected were major. A review of the pump station log sheets from April 1, 1991, to March 1, 1992, showed that gas detectors at Brenham station activated eight times, four of which were during nonwork hours. In each instance, the activations were not caused by gas. When on-site personnel either replaced or recalibrated the detectors, the detector system promptly resumed normal operation. In postaccident testimony, the company executive officer stated that while he wished that the gas detectors around the brine ponds performed more reliably, he believed that the current devices were the best that the company could obtain when they were installed.

Properties of HVLs in the Brenham Cavern.¹² In the cavern, stored HVLs remain in liquid form because of the pressure that the brine exerts on them. The HVL mix stored at Brenham station comprised more than 40 materials, primarily ethane, propane, and butane. The table below shows the vapor pressure¹³ and other selected constants of the three principal compounds in this HVL. Ethane, propane, and butane are all colorless, odorless, nontoxic, flammable gases. If a person inhales any one or a mix of these three gases at low concentrations in air (5 percent or less), the gas(es) will not cause any definite symptoms. At higher concentrations, each gas has an anesthetic effect and can act as an asphyxiant as it displaces the oxygen in the air. In liquid form, each product can freeze tissue if it comes in contact with the skin. One

¹² *Handbook of Compressed Gases*, Second Edition, Compressed Gas Association, 1981, and *Engineering Data Book, Volume II*, Gas Processor Suppliers Association, 1987.

¹³ At any given temperature, the pressure needed to keep an HVL as a liquid is called its vapor pressure.

cubic foot of HVL will generate several hundred cubic feet of vapor. For example, at 60° F, 1 cubic foot of liquid ethane, propane, and butane will form 295, 273, and 254 cubic feet of vapor, respectively, if reduced to atmospheric pressure.

HVL PROPERTIES	ETHANE	PROPANE	BUTANE
Vapor pressure at 70°F	544 psig	109.73 psig	16.54 psig
Specific gravity of gas at 60°F, 1 atm	1.0469	1.5226	2.0068
Specific gravity of liquid at saturation and 60°F	0.3562	0.5070	0.5840
Flammable limits in air, by volume	3.0-12.4%	2.1-9.5%	1.8-8.4%
Flash point	-211 °F	-156 °F	-101 °F

Table 2. Properties of ethane, propane, and butane.

The Dispatch Center.--The dispatch center in Tulsa monitors and controls all pipeline product flow operations by means of a telemetry system called the Supervisory Control and Data Acquisition (SCADA) system. Before the Brenham accident, the center had three SCADA work stations or "boards." One board controlled the two Texas systems, Seminole and Snyder pipelines (see figure 11); a second board controlled MAPCO's northern division system; and the third controlled MAPCO's western division system.

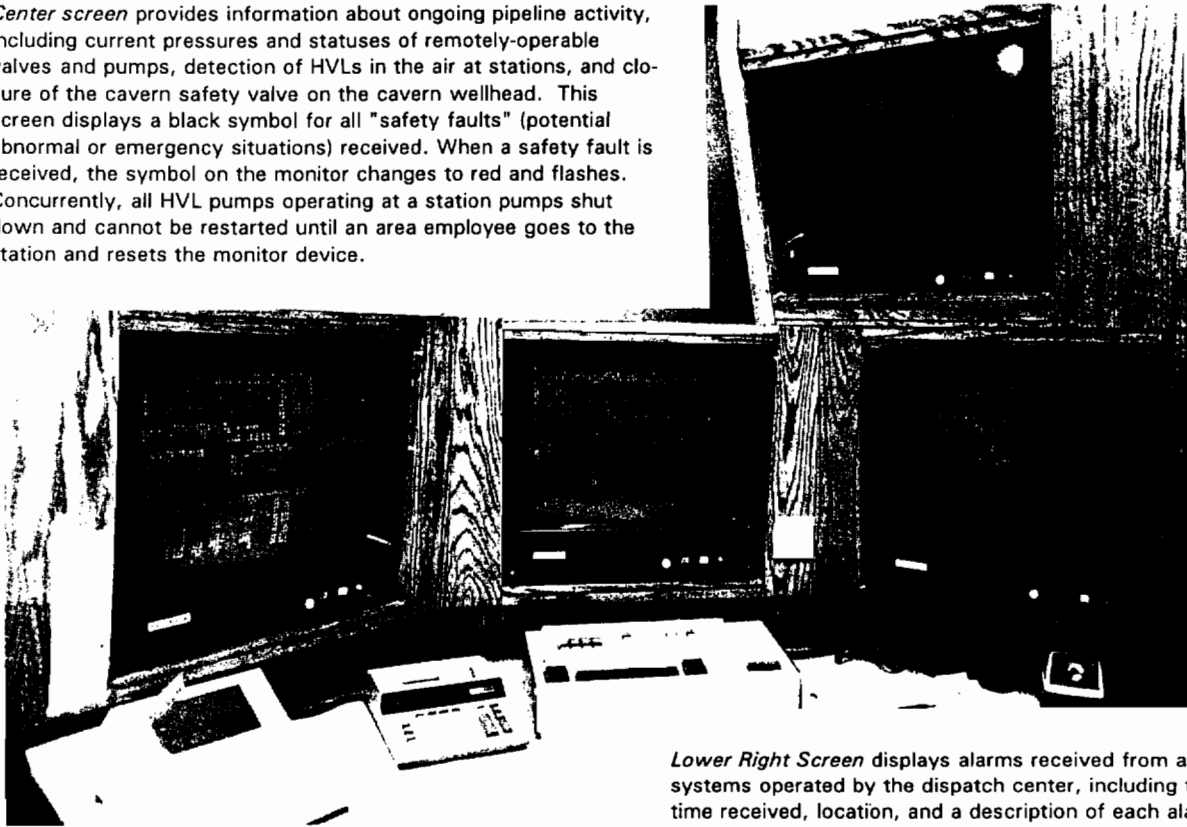
The SCADA system collects data from all monitored points within the Seminole pipeline system and MAPCO's systems, processes and displays the data on monitors, identifies operating data that are not within preselected parameters and displays them as alarms on monitor screens, displays a schematic of the pipe system, and stores operating data for later retrieval.

Dispatchers communicate with the SCADA telemetry system and the computer data base by typing in commands on a keyboard. In this manner, dispatchers are able to "command" changes in remotely operable valves, pump operations, and product flow routing on a given system and can retrieve information from the computer data base. Each of the four monitor screens displays data received about the pipeline system in different functional formats.

The SCADA telemetry system receives information from various monitoring devices throughout the Seminole pipeline system and updates the system information every 15 to 20 seconds. From Brenham station, the monitor screens at the Seminole/Snyder board display information such as shown in figure 12.

Upper Right Screen can be used to call up various information maintained in the dispatch center's computer database. Using this screen, the dispatcher can view piping diagrams for the stations, sections of the pipeline between stations, or historical data on pressures and flows that are in the computer database.

Center screen provides information about ongoing pipeline activity, including current pressures and statuses of remotely-operable valves and pumps, detection of HVLs in the air at stations, and closure of the cavern safety valve on the cavern wellhead. This screen displays a black symbol for all "safety faults" (potential abnormal or emergency situations) received. When a safety fault is received, the symbol on the monitor changes to red and flashes. Concurrently, all HVL pumps operating at a station pumps shut down and cannot be restarted until an area employee goes to the station and resets the monitor device.



Left screen displays the Seminole mainline flow rates and meter readings, and the pump pressures, HVL flow rates, valve status, location of different batches of HVLs moving through the system, and "safety faults" for the Snyder system. The computer records and permanently stores pressure and flow rate information at 15 minute intervals; the dispatcher can retrieve this information at any time.

Lower Right Screen displays alarms received from all systems operated by the dispatch center, including the time received, location, and a description of each alarm. The most recent alarm appears at the bottom of the screen and then moves up as subsequent alarms are received until it moves off the screen. Each alarm is also recorded by a printer in the dispatch center at the same time it appears on the screen, thereby providing an audible notice of an alarm. This screen affords dispatchers the opportunity to assisting one another without leaving their assigned stations, such as when many alarms are received or when a dispatcher needs to take a break.

Figure 11. The SCADA "Board" for the Seminole pipeline.

Personnel Information

The individuals discussed below include field personnel who were on site at Brenham station and dispatch personnel who were monitoring the Seminole/Snyder pipelines on the morning of the accident. The area safety regulations coordinator is also included.

Brenham Station.--Area operators, technicians, pipeliners, and an assistant supervisor are required to perform specific tasks at Brenham station each weekday. Before the accident, the facility was an "unattended station" in that the dispatch center in Tulsa remotely controlled product transport to and from the station and area personnel were not required to remain on-site once they had performed the required morning meter readings and other necessary functions, such as maintenance.

Assistant Maintenance Supervisor.--Before joining MAPCO, the assistant maintenance supervisor worked as an operator and a maintenance specialist for Colorado State Gas. He joined MAPCO in 1984 as a technician in the oil and gas division. As assistant maintenance supervisor, he supervised the technicians and was responsible for all technical maintenance performed on the 120 miles of mainline pipe from Burnet to Cat Springs.

Technician.--Before joining MAPCO in summer 1987 as a technician trainee, the technician worked in power (line) distribution. As a technician, his primary responsibility was to maintain electrical equipment, such as the pumps, meters, transformers, motor-operated valves, and calibrating switches. He also performed inspections and tests required by the Government and/or the company and some general station maintenance. He and several other technicians within the division rotated being on-call during nonduty hours for the purpose of checking out any abnormal reading or emergency signal that the Tulsa dispatch office might receive from equipment in their work area.

Technician Trainee.--An employee of MAPCO since summer 1991, he performed the same duties as a technician under the supervision of experienced personnel. As a trainee, he was not subject to being on-call to respond to emergency calls.

Flow rate of HVLs entering the station from the Bryan Lateral;

Flow rate of HVLs being injected into and removed from the cavern;

Status of pump operations (on or off) and the pump suction, case, and discharge pressures;

Status of remotely operated valves: open, closed, or in the process of changing positions;

Pressure of HVLs in the 14-inch mainline, the meter runs, the Bryan Lateral at the station, and the pipe between Seminole and Coastline;

Indication that the cavern safety valve on the cavern wellhead had closed; and

Detection of HVL in air by any one of the many combustible gas detectors located around the brine ponds and other locations within the station.

Figure 12. Types of data displayed by the SCADA monitors.

Pipeliner.--Before joining MAPCO in fall 1990, he had worked in the pipeline industry for about 12 years. As a pipeliner, he was responsible for maintaining the piping and nonelectrical equipment at a station and for performing general maintenance operations, such as taking care of the grounds. He also served as a system operator when needed. Originally assigned to Sugar Land, Texas, he transferred to Brenham about 6 months before the accident. His first-line manager, the supervisor of maintenance, was at the division office in Sugar Land.

Area Operator.--The area operator initially was assigned to Brenham station in 1990 as a pipeliner. After completing the company's area operator training course in April 1991, he assumed the duties of area operator, which entailed reading the various meters at the station and calculating actual cavern volumes, which he reported on the Daily Operating Volume (DOV) reports.¹³ He also performed meter accuracy tests and operated all of the station's manually run equipment that impacted product transfer in the system piping. The area operator at Brenham station reported to the operations supervisor, who was based in Sugar Land.

Lab Technician.--The lab technician began work with MAPCO in February 1973. Since March 1981, he had been assigned to the Brenham station, serving in a variety of positions, including technician trainee, terminal man, and area operator. He was promoted to lab technician supervisor in May 1990. His first-line manager, the operations supervisor, was at the division office in Sugar Land.

Regulatory Coordinator.--The regulatory coordinator had worked 14 1/2 years for MAPCO. Before transferring to Sugar Land, he had worked as a fractionator in Kansas for about 3 years and then as an area operator at Scullytown, Texas, for 8 years. As the area regulatory coordinator, he was based at the division office in Sugar Land and reported to the division manager.

The Dispatch Center.--On the eve of the accident, the Seminole/Snyder board was manned by a dispatcher trainee and an experienced dispatcher, who was serving as trainer and overseeing the work of the trainee. About 6:30 a.m. on April 7, the nightshift dispatchers for the Seminole/Snyder board were relieved by the dayshift dispatcher.

Dispatcher (Trainer).--He had worked for MAPCO since 1981. His first assignment was as a pipeliner with the maintenance crew. In 1984, he transferred to the operations department, where he worked as an area operator for 2 years and then as a meter technician for almost 4 years. In 1989, he completed all required knowledge improvement courses and on-the-job training to become a dispatcher. Before reporting to work on the eve of the accident, the dispatcher (trainer) had worked the 7 p.m. to 7 a.m. shift on April 3, 4, and 5.

¹³ The measurements and calculations that an employee performed in preparing the DOV report appear under "Operations and Maintenance, Inventory Operations."

Dispatcher Trainee.--He began work as a pipeliner at Brenham station in July 1989. In July 1990, he transferred to Hobbs station, where he worked as a utilityman until February 1992. At that time, he transferred to Tulsa to start training to become a dispatcher. The last time that the dispatcher trainee had worked before the eve of the accident was the 7 a.m. to 7 p.m. shift on April 4.

Dispatcher.--The dispatcher who was manning the Seminole/Snyder board at the time of the explosion had worked for MAPCO since 1974, when he was hired as a pipeliner. Three months later, he transferred to the Conway, Kansas facility, where he worked as a fractionator for 5 years. He had been a MAPCO dispatcher since 1979. Before reporting to work on the morning of April 7, he had last worked the 7 p.m. to 7 a.m. shift on April 4.

General Employee Training.--Pipeline Safety Regulations at 49 CFR 195.403, "Training," stipulate that "Each operator shall establish and conduct a continuing training program to instruct operating and maintenance personnel ..." in the following areas: normal operating procedures as outlined in the operator's employee operating handbook, characteristics of HVLs, identification of emergency situations and appropriate response actions, procedures for controlling or minimizing accidental releases, procedures for fighting fires and proper use of fire fighting equipment, and precautionary measures when repairing facilities.

The MAPCO training program for employees began on their first day with the company and continued throughout their employment. Training included orientation and initial instruction, mandatory and optional self-study courses, on-the-job training (OJT), in-house and contracted training, and safety seminars.

Orientation.--According to an outline of the orientation course, employees were briefed about the various sources from which they could obtain information about pipeline operations. Instruction included explanations of hazardous material labeling, fire extinguisher use, and company policies regarding safety clothing and drugs. Much of the instruction was presented in the form of videos. Instructors also told employees about available written material, such as procedural manuals, pipeline and pump station diagrams, and the material safety data sheet book. Employees were given several safety items, including a hard hat, safety glasses, goggles, work gloves, earplugs, a rainsuit, and rubber boots.

Self-study Courses.--Within 6 months of their hiring date, new employees had to complete the first eight courses of a "Knowledge Improvement Program," a self-paced, 36-course correspondence series. MAPCO contracted development of its correspondence program from Technical Publishing Company, a division of Telemedia, Inc., which specializes in developing standard basic training manuals and films for schools and industries. Required courses included blueprint reading, shop math, hand tools, plant safety, piping systems, product transportation, properties of products, and safety in product handling. In each course, the end of each lesson chapter had a self-check quiz and a summary of the important principles covered in the chapter.

As an employee completed a course, MAPCO sent him a final test to be completed and returned to the company for grading. The company maintained a record of the final test results in the employee's permanent file. According to company policy, which was confirmed by employee testimony, employees could neither be promoted from their initial position nor receive a pay raise until they had successfully completed the eight required courses. Employees could take the additional 28 courses of the Knowledge Improvement Program at their own pace and were permitted to keep course books for use as on-the-job reference materials.

Employees who had gained knowledge of the subject matter from prior work experience or coursework had the option of taking a pretest. If they scored 70 percent or higher on the pretest, they were not required to take the correspondence course. MAPCO also maintained records of employees' pretest scores in their personnel files.

OJT Instruction.--During OJT, a new employee was paired with an immediate supervisor and/or experienced co-worker, who performed required procedures at a worksite while the novice watched. Employee testimony and personnel records showed that the "trainers" had never received specialized training or coursework to prepare them to be instructors.

After the new employee observed the trainer a sufficient number of times to express confidence in his ability to perform the procedures, the experienced employee supervised while the novice performed a task. According to MAPCO, a new employee was allowed to perform a given task unsupervised only after repeatedly demonstrating the ability to perform the task in a supervised situation.

From interviews and a review of training manuals and guidelines used by field and dispatch personnel, Safety Board analysts determined that employees had few or no written procedures specific to their positions. For example, employees who performed volume calculations either at Brenham station or at other stations did not have a written protocol to which they could refer. Available manuals included one that explained general procedures and one that contained product-specific and safety information.

While an employee was in the OJT phase, the trainer treated each procedural task separately. If a trainer determined that the new employee was proficient in some minor, non-dangerous field operating tasks, he might allow the trainee to perform those duties unsupervised but require that the trainee perform more involved or potentially dangerous tasks only when a senior person was present. Company policy stated and employee interviews confirmed that the OJT phase was no fixed period; new employees remained in the phase until they demonstrated they could perform all tasks correctly.

Personnel records showed that with one exception, all dispatchers were experienced in pipeline field operations before being selected as dispatcher trainees. The dispatcher training program did not include formal classroom instruction; all instruction was OJT. A trainee initially

sat with and observed as an experienced dispatcher operated one of the three dispatch boards during the 12-hour workshift. As information appeared on the monitors, the trainer explained what was being shown and what operations had to be performed. In the next phase of dispatcher OJT, the trainee sat at the keyboard and performed the required functions under the supervision of a trainer seated nearby.

During the several months that a trainee was in dispatcher OJT, the individual rotated among all experienced dispatchers for training and supervision and worked each of the three boards at the dispatch center. Trainees were exposed to different facets of operations. For Brenham station, trainees were instructed how to monitor and/or respond to the readings and alarms listed earlier in this report in figure 12.

Toward the end of the dispatcher OJT program, trainees were given a mock drill involving a leak or product release from a pipeline and were evaluated on their response actions. Trainees had to correctly identify and simulate calls to the appropriate field and public emergency response agencies and take corrective action by operating the remote equipment available to isolate the problem. The trainee was required to handle all essential tasks with no prompting while the head dispatcher and other dispatchers observed and evaluated the trainee's performance.

Interviews with dispatchers revealed that trainees were not required to demonstrate they could handle an abnormal cavern situation as part of the drill. MAPCO also did not require that dispatcher trainees take a final written examination to become full dispatchers. Whether an individual successfully completed dispatcher training was based solely on the judgment of the head dispatcher and dispatcher trainers who supervised the trainee during the OJT training phase. Company supervisors had the final decision whether and when a trainee was qualified for promotion to dispatcher.

Safety Meetings.--Company records show that between January 1, 1991, and the date of the accident, supervisory personnel and the division regulatory coordinator conducted 23 employee safety meetings systemwide. These in-house seminars were held both at the stations and on a divisionwide basis. Accordingly, personnel based at Brenham station attended ten safety meetings that the company held at the station and at the Sugar Land division warehouse. The division manager, supervisors, and regulatory coordinator determined the meeting agendas, which, among other subjects, included emergency response procedures. Additional safety meetings were conducted whenever the division manager or one of the supervisors determined that a matter required immediate attention, such as learning how to use new equipment or the impact of a new government regulation.

Safety meetings were structured to foster discussion of the safety topic and/or procedures. For instance, during an October 1991 safety meeting on abnormal operations, employees were given five emergency scenarios. Of the five, three scenarios dealt specifically with the Brenham area and included an HVL release from the cavern. Personnel were to evaluate the cause of the

problem and what steps should be taken to resolve it. The scenarios were first completed individually, then later discussed by the group. Following the safety meetings, class participants usually were not required to take written tests or demonstrate proficiency in emergency drills. Safety Board investigators determined from a review of safety meeting agendas and from interviews that Brenham station employees had attended sessions that covered emergency response procedures for handling major HVL releases.

Dispatchers and on-scene personnel were provided with video tapes and the procedural manual discussing abnormal operations and emergency procedures. Investigators found that the material provided did not include written procedures for either the dispatchers or on-scene employees that would assist them in gathering and reporting product-release information.

All materials provided to both dispatch and on-scene personnel stressed that the dispatcher has the authority to shut down the pipeline system and implement emergency procedures without having to seek supervisory approval. The dispatchers are considered the main link in communications among the emergency responders. Their critical procedures include calling out field personnel to check out suspected damage, shutting down all pumping units and closing fire valves, notifying company personnel and local people designated as emergency contacts, directing personnel to the leak area, monitoring the SCADA for pressure and flow information, and informing the supervisor of abnormal operations and what action has been taken to correct it. In handling an emergency, a dispatcher can request assistance from other dispatchers working the same shift. However, MAPCO did not provide procedures or training that identified the most effective allocation of emergency response tasks among the dispatchers.

According to the procedural manual, when handling an abnormal or emergency situation, the responsibilities of on-scene personnel included closing valves, establishing road blocks, evaluating the hazard, warning people, and in general, preventing damage to life and property. One company representative capable of evaluating, planning, and coordinating leak-site activities was to go directly to the leak site, take charge, and determine the proper way of controlling the liquid or vapor release.

Supplemental Training.--In addition to the safety meetings, MAPCO either conducted or contracted vendors to conduct in-house schools and seminars. For example, an in-house school for area operators and technicians was conducted every year to train new employees and update experienced personnel. Between January 1, 1991, and April 6, 1992, MAPCO conducted five in-house schools and contracted one vendor class that provided more detailed training on equipment maintenance. Safety Board investigators determined that MAPCO encouraged employees to attend schools conducted by independent organizations and vendors on company time and at company expense.

Performance Evaluations.--Federal regulations stipulate that "at intervals not exceeding 15 months, but at least once each calendar year," operators must review with personnel their

performance in meeting the objectives of the training program in the six areas listed at CFR 195.403 (see figure 13).

Safety Board investigators determined that company supervisors routinely monitored the work of their subordinates. The acting area manager at the time of the accident said that he checked calculations, inspected on-site, and held discussions with his employees to determine whether they were correctly performing their responsibilities.

A Safety Board inspection of personnel records indicated that company supervisors formally reviewed their employees' work performance annually and rated them on such factors as dependability, attention to detail, and cost consciousness. Personnel files also contained records of training that each employee had completed. A MAPCO representative testified that company managers annually reviewed and made adjustments to the established training program to ensure the effectiveness of their training.

Carry out the operating, maintenance, and emergency procedures that relate to assignments.

Know the characteristics of hazardous liquids, including the flammability of mixtures with air, odorless vapors, and water reactions.

Recognize conditions likely to cause emergencies, predict the consequences of facility malfunctions or failures and hazardous liquid spills, and take appropriate corrective action.

Take steps necessary to control any accidental release of hazardous liquid and minimize the potential for fire, explosion, toxicity, or environmental damage.

Learn the proper use of fire fighting procedures and equipment, fire suits, and breathing apparatus by utilizing, where feasible, a simulated emergency.

(For maintenance personnel) Safely repair facilities using appropriate special precautions.

Figure 13. Excerpts from 49 CFR 195.403.

Dispatcher Workshifts.--Dispatchers worked a rotating schedule of 12-hour shifts. According to MAPCO, a typical work cycle required that a dispatcher work two or three day shifts, which were scheduled from 7 a.m. to 7 p.m., have 2 days off, and then work two or three consecutive night shifts, which were scheduled from 7 p.m. to 7 a.m. The dispatcher then had 2 days off before the above rotational schedule began anew. This rotational cycle continued throughout the month.

The three dispatchers interviewed by Safety Board investigators stated that they arrived 20 to 30 minutes before their scheduled shift so that dispatchers whose shift was ending could brief them about any situations that might require particular attention and operations that were to be conducted during the upcoming shift.

Safety Board investigators reviewed the work schedule sheets of dispatchers from March 1 to April 7, 1992. They determined that the dispatcher trainer had worked the night shift 4 nights in a row before the morning of the accident. The dispatcher trainee had worked the day shift on April 4 and had been off 60 hours before starting his night shift on April 6, the eve of the accident. The dispatcher who relieved the dispatcher trainer and trainee at the Seminole/Snyder board the morning of the accident had worked the midnight shift on April 3

and had been off 72 hours. Work schedule sheets also showed that two company dispatchers had worked 8 consecutive days without a day off during the 2-month period.

From interviews, Safety Board investigators determined that the dispatchers did not have regularly scheduled breaks. Dispatchers were allowed to leave their stations momentarily to use the restroom or get a snack. While a dispatcher was away from his board, the other dispatchers would listen for alarms printing out on the alarm logger, which recorded alarms received from all pipeline systems monitored by the Tulsa dispatch office. If a dispatcher heard an alarm printing on the logger that was not on his console monitor, he could switch his screen to bring up the information for the other pipeline system. Dispatchers usually ate their lunches at their boards while they continued to monitor the SCADA.

Toxicological Testing.--The Pipeline Safety Regulations at 49 CFR 199.11 stipulate the following in regard to postaccident drug testing:

As soon as possible, but no later than 32 hours after an accident, an operator shall drug test each employee whose performance either contributed to the accident or cannot be completely discounted as a contributing factor to the accident.... An operator may decide not to test under this paragraph but such a decision must be based on the best information available immediately after the accident that the employee's performance could not have contributed to the accident or that, because of the time between that performance and the accident, it is not likely that a drug test would reveal whether the performance was affected by drug use.

About 31 hours after the explosion, MAPCO managers required urine samples from the three dispatchers who were monitoring the Seminole board on the eve and the morning of the accident. Field personnel at the Brenham station were not asked to submit samples.

According to a company spokesperson, MAPCO did not test its dispatchers earlier because the company thought that Coastline's pipeline was the source of the release. He further stated that MAPCO did not require that field personnel submit to testing because the company believed that the accident did not result from any action performed by an on-site employee. The State agency responsible for investigating this pipeline accident, the TRC, did not require that on-scene employees submit to postaccident drug testing.

Samples were taken to Smith Kline-Bioscience, a National Institute for Drug Abuse (NIDA)-certified laboratory in Dallas, Texas, where they were analyzed for amphetamines, cocaine, PCP, marijuana, and opiates. The drug test results were negative.¹⁴

¹⁴ Current Federal regulations do not require that blood samples be submitted for toxicological testing or that an individual be tested for alcohol.

Operations and Maintenance

According to a company spokesperson, MAPCO's operations called for timely delivery of the HVLs. Storage of mixed HVLs in caverns was viewed as a temporary measure to afford the company a more economical means to operate the entire pipeline system. MAPCO's contract with processing plants along the Bryan Lateral obligate the company to take all products that the plants produce so long as operating conditions permit. If product cannot be stored in the cavern, dispatchers sometimes must inject Y-Grade¹⁵ products into pure products or shut down the plants, either of which is very costly to the company.

Inventory Operations.--As mentioned previously, each morning about 7 a.m., an employee prepared the Daily Operating Volume (DOV) report for Brenham station. He inventoried product volume by recording readings from the Bryan Lateral meter, the cavern meter, and the Coastline meter on a worksheet. According to a company spokesperson, the employee then corrected the readings for meter error¹⁶ and converted all measured volumes to a standard temperature and pressure to allow direct comparisons of measured volumes, a procedure that is standard in the industry.

Employees corrected all measured volumes to 60° F and equilibrium pressures. Employees next corrected the meter reading volumes based on the applicable volume correction factor and then calculated the net volumes of HVLs received at the station from Coastline or the Bryan Lateral, delivered from the station to Coastline, delivered to and from the cavern, and the volume of HVLs stored in the cavern. The volume correction factor was derived using the weekly derived density volume correction factor (based on analysis of a sample of the HVL mix delivered to the Bryan Lateral from plants) and the flow-weighted average product temperature and pressure. The meter correction factor was based on periodic flow proof tests. Once the net volumes were calculated, the area operator entered the data into a computer at the station to create a DOV report.

The DOV report was sent to Tulsa, where the scheduler used it to make decisions on future HVL transportation within the Seminole pipeline system. The DOV report was also sent to the operations supervisor of Seminole's South Texas Division, who checked calculations on the DOV for mathematical accuracy. The Safety Board determined that the operations supervisor

¹⁵ MAPCO transported several grades of HVLs in its pipeline system: pure products, such as propane and iso-butane; mixtures of pure products, such as ethane and propane; and mixed products known as Y-Grade.

¹⁶ According to a company spokesperson, employees at Brenham periodically tested the accuracy of the meters. A meter was tested whenever it had logged a given barrel volume dependent on the size of the device. To be acceptable, the test repeatability factor had to be within +/- 0.02 to 0.05 percent for five consecutive readings during the proof test. Additionally, a new meter factor for a meter had to be within +/- 0.25 percent of the previous meter factor and within +/- 0.5 percent of the original meter factor. A meter failing to meet these criteria was removed from service.

could not check the correction factors or temperature and volume computations that employees used because this information was not shown on the DOV report.

According to a company executive officer, Y-Grade product, which contains some gasses, is a very compressible material that always needs to be measured at all incoming and outgoing flow points if measurements are to balance. At Brenham station, product was not metered as it entered the 14-inch mainline. Y-Grade HVLs received from the plants into the Bryan Lateral were metered, and the metered volume was adjusted based on the representative density test results, the meter error factor, and the pressure and temperature at which the HVL was metered. The flow from the Bryan Lateral into the station was similarly metered and corrected. The sum of the corrected volumes for the plant deliveries was then compared, both daily and weekly, to the corrected volumes measured by the Bryan Lateral meter at the station. Any variations were investigated and, if necessary, corrective action was taken. Comparison of HVL volumes received at and transported from the station could not be made because HVLs transported from the station into the 14-inch mainline were not metered. Thus, the company could not compare the volume of HVLs entering the station to the volume leaving the station.

After the accident, MAPCO audited the work performed by area operators in developing the DOVs from the last time the cavern was empty (July 13, 1991) until the last DOV prepared before the accident (April 6, 1992). After correcting the errors found and recalculating the daily cavern volumes, company auditors reduced the quantity of HVLs entered into the cavern by 19,196 barrels and reduced the quantity of HVLs removed from the cavern by 50,872 barrels. In their recalculations, the auditors included 19,429 barrels injected into the cavern between 7 a.m., April 6, 1992, and 7 a.m., April 7, 1992.

As a result of the audit, the company determined that the cavern held 319,981 barrels at the time of the accident, about 32,000 more barrels than the 288,305 barrels reflected in its records. The audit showed that MAPCO had exceeded its self-imposed 300,000-barrel maximum cavern storage volume on the following days: March 2, 4, 9, 11, 12, and 19, and April 6 and 7. The company's audit also showed that the volume in the cavern was greatest on March 11, 1992. On that day, 9,515 barrels were added to an existing quantity of 313,047 barrels, for a storage total of 322,562 barrels. Company records show that on March 11, the cavern contained more product than on April 7 and did not release product.

As part of its investigation, the Safety Board reviewed the pipeline company's audit, the area operator's worksheets, and the DOV reports for the period between July 13, 1991, and April 6, 1992. The Board determined that in a period spanning fewer than 260 days, on-scene employees made almost 700 errors in determining the volumes of product entered into and removed from the cavern. Of these errors, 2 percent were misapplication of metered volumes; 12 percent, incorrect math; 17 percent, use of wrong meter correction factor; and 69 percent, use of incorrect HVL temperature factor in determining the volume correction factor. The Safety Board determined that all employees who prepared DOVs at Brenham station had made these types of errors.

MAPCO's accounting procedures called for its caverns to be emptied annually to determine the accuracy of operations. Brenham cavern had been emptied more frequently. Each time, the company compared the product volume that its records showed had been stored in the cavern with the actual product quantity withdrawn. Before the April 1992 accident, the company had emptied Brenham cavern 160 times. In 1982, the station's first year of operation, MAPCO emptied the cavern 42 times. After that, the company emptied the cavern each time operations permitted. The number of emptyings per year were as follows: 27 in 1983, 8 in 1984, 13 in 1985, 19 in 1986, 17 in 1987, 15 in 1988, 7 in 1989, and 8 in 1991.

Before the 1992 accident, records show that measurement accuracy varied greatly. Errors ranged from 9.13 percent less to 59.97 percent more than the volume indicated on the DOV reports. Figure 14 shows MAPCO's cavern management measurement errors relative to the respective total flow in and out of Brenham cavern for the 4-year period from 1988 through 1991. During this time, most of MAPCO's cavern volume measurement errors were within its accuracy goal of 0.25 percent when total volume flowing into and out of the cavern between emptyings exceeded 1 million barrels. However, between February 20 and July 31, 1989, the company experienced a 1.33 percent error when 1,830,480 barrels of HVLs flowed through the cavern. On several occasions when total volume through the cavern was less than 1 million barrels, MAPCO experienced errors over 1 percent and up to 2.6 percent.

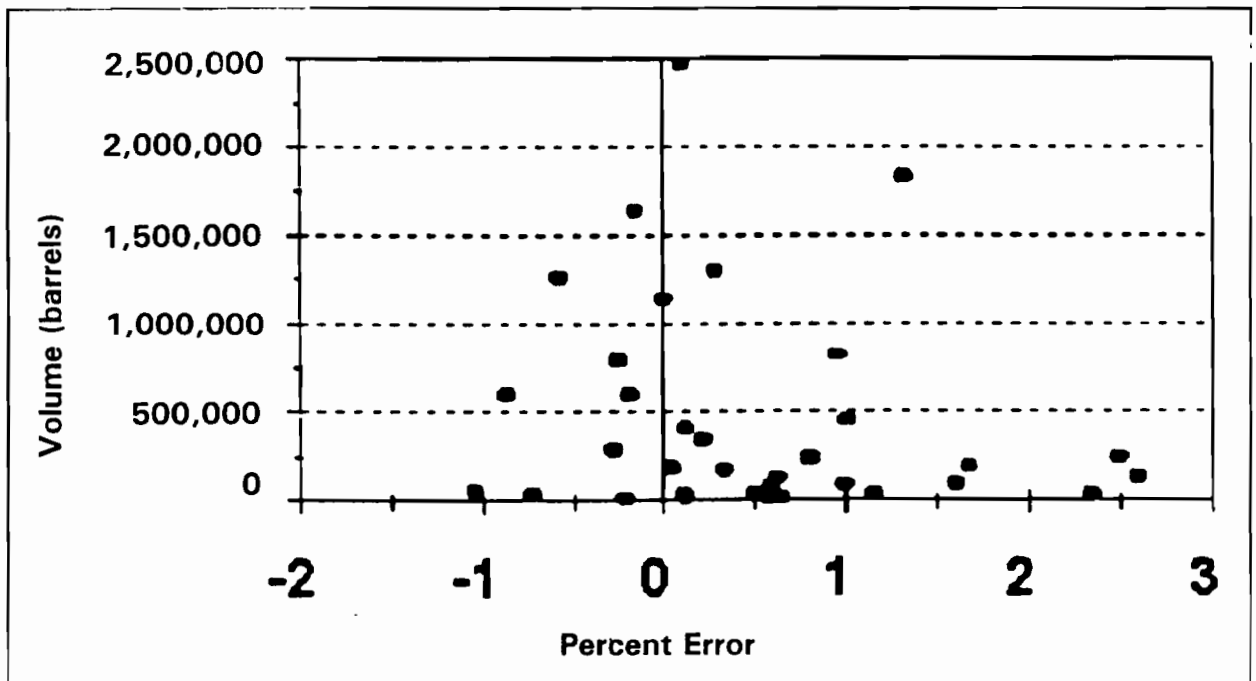


Figure 14. Measurement accuracy versus cavern flow.

Records show that before the accident, the maximum quantity of HVLs that MAPCO pumped into and from the cavern between emptyings was 2,685,095 barrels during the 4-month period between February 29, 1984, and July 7, 1984. In the 9 months between July 12, 1991,

when the cavern was last emptied, and the accident, the company had pumped almost 5 million barrels into and from the cavern. The company's senior vice president testified that he became aware of measurement inaccuracies at Brenham cavern only after the accident. He said that some weeks before the April 1992 accident, the division manager had recommended that the cavern be emptied because of the high volume that had passed through the cavern since it was last emptied. The division manager had been given the go-ahead to schedule the cavern for emptying, but he had not set a date to do so before the accident occurred.

Scheduling.--Based on the orders received during the month, a scheduler in Tulsa developed schedules for moving HVLs within the Seminole system, including those that were to be temporarily stored in or removed from underground caverns.

The scheduler developed a weekly agenda on the HVLs that were to go into the mainline from plants and caverns. From the weekly agenda, he developed a schedule showing who was to make the deliveries, when deliveries were to be made, and at what rate they were to be made. The schedule was sent to dispatchers as instructions that they were to follow and to the employees at stations to inform them of planned operations.

The scheduler used information provided daily, such as deliveries that dispatchers indicated were made to customers, the HVL quantities for which customers contracted, and the meter measurements showing the quantity of HVLs stored in caverns, to determine whether the transportation schedules that he prepared should be altered.

When scheduled deliveries to a cavern approached the maximum working storage capacity established for that cavern, the scheduler discussed the situation with station employees so that they could take whatever precautions they believed necessary, such as having employees be on-site at the station. From interviews, the Safety Board determined that the company followed such a procedure on March 11, 1992. When the scheduler believed that the quantity of product scheduled to be stored at Brenham would put the cavern at its maximum working capacity of 300,000 barrels, he notified area personnel, who stayed on-site to monitor the brine tube for HVLs and to manually close the cavern valve if the brine tube contained HVLs.

Role of the Dispatcher.--According to MAPCO, to ensure the least disruption to future customer deliveries, dispatchers maintained logs so that they had a reasonable estimate of where HVL batches were located within the pipeline system and of the quantity of HVLs in the caverns. Dispatchers were required to plot the locations of batches every 4 hours and to be aware of the storage within each cavern by reviewing the scheduler's instructions and the dispatch log, which showed cavern deliveries and withdrawals. If confronted with a situation not covered by the scheduler's instructions, such as an emergency, a dispatcher might have to reroute or mix products in the pipeline or shut down a plant providing HVLs for deliveries. Company procedures did not allow dispatchers to knowingly exceed the maximum working capacity of underground caverns.

According to MAPCO, when a dispatch board received a gas alarm from an unattended station, the alarm was to be considered a potential rather than an actual emergency. Operating procedures required that the dispatcher immediately contact a technician to respond to the station to determine the reason for the alarm.

Tests and Maintenance of Safety Equipment.--While MAPCO required that employees check the cavern shutdown system every 6 months to ensure that it was functioning properly, the company had no written guidelines outlining the procedures to follow. An employee learned how to check the cavern shutdown system through OJT under the supervision of a technical supervisor or experienced technician.

In postaccident testimony, the technician who performed the March 1992 test recounted the steps that he followed when checking the shutdown system. He stated that he secured the cavern safety valve in the open position so that it did not operate during the test. As a safety precaution, he closed the valve near the Barksdale switch on the brine sensing line (steel tubing) before disconnecting it from the tubing to the Barksdale switch. After disconnecting the sensing line, he reopened the valve so that brine could flow through the line.

The technician next installed a hand-operated pump to the inlet of the Barksdale switch, applied pressure, and watched the switch to see whether it activated at 100 psig pressure. He said that during the March 1992 test, the switch tripped at 89 psig pressure, so he adjusted the switch setting. On retesting, the switch activated at 100 psig. When the switch activated, he checked the tripping lever on the solenoid valve to ensure that it released the chain holding the cavern safety valve open. The system tripped at the set pressure during three consecutive tests. The technician said that he then reconnected the sensing line to the Barksdale switch. He testified that no other checks of the sensing system were scheduled until the next 6-month inspection.

At 6-month intervals, the technician calibrated the hazardous gas detectors using the manufacturer's test procedures and a test gas of propane in air. The technician also periodically monitored the gas detector units and recalibrated or replaced them as necessary. He assessed the performance of the detector units by periodically viewing the readings on the station control monitor. When the monitor indicated a small increase in the expected voltage for any of the detectors, he used a hand-held gas detector to check the area of the station monitored by the detector in question. If no HVLs were detected, the detector was recalibrated and/or replaced.

Safety Oversight.-- Each division manager designated an employee to be the regulatory coordinator for the division. As such, the individual was responsible for reviewing both existing and proposed regulations, including safety regulations, that applied to Seminole's operations and for keeping the division manager up-to-date on regulatory requirements. The division manager determined which requirements applied to his operations and directed the regulatory coordinator to implement them. Implementation of regulatory requirements was accomplished through coordination with the division's supervisors. The regulatory coordinator also received guidance

from a regulatory and safety coordinator from the headquarters engineering department and through periodic meetings with other division regulatory coordinators.

In early 1992, before the accident, the South Texas Division formed a Safety Inspection Committee, which was composed of the regulatory coordinator and representatives from the operations, maintenance, and technical groups, to inspect the stations and valve sites along the route of the pipeline for safety and environmental problems. Results of each inspection were recorded and provided to the division manager, who forwarded the report to the appropriate supervisors for corrective action. Supervisors receiving the report were required to report to the committee what actions had been taken to correct identified problems. After receiving a report on corrective actions taken, the safety inspection committee revisited stations and locations to ensure the adequacy of the actions taken. The Safety Board determined that the committee had planned a review of Brenham station, but had not scheduled an inspection before the the accident occurred.

Abnormal Operating Procedures.--The MAPCO employee procedures manual,¹⁷ in part, states that the pipeline systems operated by MAPCO:

are designed and installed to operate as FAIL SAFE systems. Each location is equipped with instrumentation and controls that will maintain operating conditions within the set, safe, normal operating parameters. The pipeline systems are controlled remotely by a central dispatching section via a state-of-the-art computerized telemetering system. Normal operating parameters have been established for the systems covering such items as pressure, flow rates, tank levels, valve positions, unit status, communication system status, and others.

The manual also describes Outside Normal Operating Limits (ONOL) conditions, which are unintended or unexpected operating conditions that may develop on the pipeline systems but do not necessarily indicate an emergency. The manual advises that when an ONOL condition develops, in most cases, the dispatcher is automatically notified via the telemetry system. In some instances, an ONOL condition may indicate that an emergency is imminent; therefore, "each instance of an ONOL shall be investigated and analyzed. The Manager of Operations Control shall investigate and analyze the variance and respond with necessary action to resolve the abnormal condition." The manual further states that "when warranted, the central dispatcher shall notify the appropriate field personnel in the area affected."

Among conditions that the dispatcher is to monitor are pressures and flow rates for the system, such as those listed in figure 15, and the position of valves in the system. On identifying an abnormal situation, he is to have it corrected; until the ONOL is corrected, he is to maintain extra diligence. The dispatcher has the authority and is encouraged to notify field personnel to check areas of suspected damage when warranted. For a sudden decrease in pres-

¹⁷ MAPCO *Procedural Manual*, Revised March 21, 1991.

sure that is not accompanied by a change in flow rate and for which the cause cannot readily be determined, the dispatcher is to notify appropriate field personnel and request an on-site investigation.

Injection Rate (bbls/hour)		Injection Pressure (daily psig)	
Avg	Max	Avg	Max
1,500	5,000	850	1,400

Figure 15. Normal pressure and flow rates.

The procedural manual advises that storage operations may occur when terminals (stations) are unmanned; for that reason, safety devices have been built into the delivery facilities to prevent abnormal conditions from becoming emergency situations. The manual also covers appropriate dispatcher responses to a high tank level, a high delivery pressure, and loss of communications. The manual advises that in the event of high delivery pressure, a switch will automatically activate, which will cause the release of the cavern safety valve, automatically stopping flow into the terminal and closing the terminal delivery valve.

The manual also lists as abnormal conditions: loss of communications, unintended closure of valves, unintended starting or stopping of pumping units, operation of a safety device, and failure of a pressure switch. The manual reemphasizes that all facilities are equipped to fail safe.

Dispatch Center Activities on the Morning of the Accident. --Throughout the previous night, data received at the Tulsa dispatch center from the Seminole system were within normal operating parameters.¹⁸ At 3:30 a.m., the entire SCADA computer system briefly went down. When it was restarted, the Seminole system readings were still normal and remained relatively constant until just before 6 a.m. As shown in figure 16, the cavern pump discharge pressure began to decrease slowly; soon after, the suction pressure began to increase. At 6:09:34 a.m., the suction pressure had increased to 546 psig, which generated an alarm on the alarm monitor.¹⁹

At 6:09:39 a.m., a HAZGAS alarm began to flash on the monitor screen and was recorded on the computer logger (printer). In accordance with MAPCO procedures, the dispatcher trainee telephoned the on-call technician in the Brenham area to have him check out the cause of the alarm at Brenham station. At 6:09:40 a.m., the screen showed that the cavern pump had automatically shut down; 10 seconds later the monitor showed that product flow in the Bryan Lateral had dropped to zero, and an HVL flow Rate of Change (ROC) alarm flashed on the screen. The dispatcher later testified that he took no notice of the drop in flow and alarm because such events are to be expected when a pump shuts down.

¹⁸ Under normal conditions, the SCADA readings showed pump suction pressures for the mainline and cavern pumps above 524 and 474 respectively, flow rates into the cavern less than 1,500 barrels per hour, and a differential of 400 to 450 psig between the cavern pump suction pressure and the discharge pressure.

¹⁹ The SCADA computer has preset alarm points programmed into its system to alert a dispatcher of significant operating changes. Each time the cavern pump suction pressure equalled 474 psig, an alarm was transmitted to the dispatch center. The alarm was to assist the dispatcher in determining when one or two pumps were needed to keep the Y-Grade HVL above its flashpoint pressure of 325 psig. An alarm also alerted the dispatcher when the mainline pump suction pressure equalled 524 psig.

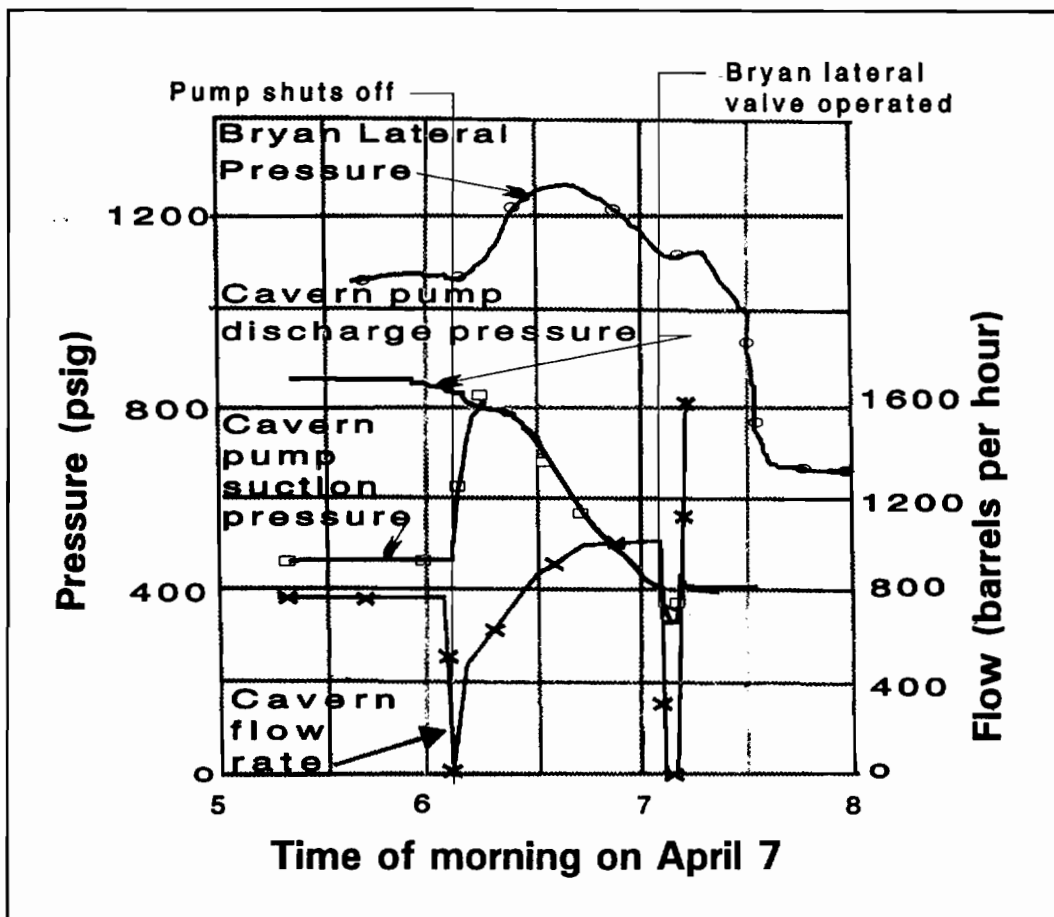


Figure 16. Graph of pressure and flow rates the morning of the accident.

By 6:15 a.m., the SCADA monitor showed that flow through the Bryan Lateral had resumed and that flows within the station piping were abnormal. Instead of the previous differential of 400 psi between the suction pressure and the discharge pressure at the cavern pump, the pressures were about equal. Flow rates for the Bryan Lateral and into the cavern were almost half what they were minutes earlier. The dispatcher said that he continued to monitor readings from Brenham station, but did not observe anything that he thought represented an emergency.

About 6:30 a.m., the dispatcher who was scheduled to monitor the Seminole/Snyder board during the next shift reported to work. The dispatchers going off duty briefed him about the status of operations on the Snyder system and told him that they had received a HAZGAS alarm from Brenham station and that they had dispatched an area technician to determine the cause of the alarm. The dayshift dispatcher said that he checked the computer alarm printout and saw that all pressure readings were within the operating norms. Beginning at 6:40:43 a.m., the dispatcher manning the Seminole board began to receive a number of pressure alarms from Brenham (see figure 17).

About 6:46 a.m., the dispatcher at the Seminole board received a call from the on-scene

technician, who told him gas was in the station yard and to call the technician's immediate supervisor.

About 7:03 a.m., the area operator, who was driving to work on CR 19, saw HVL vapor around the station. He radioed the dispatcher and advised him to shut down the Bryan Lateral. The dispatcher testified that his first action was to stop the flow of HVLs to the station. At 7:06 a.m., he closed the Bryan Lateral valve and asked his two co-workers at the dispatch center to contact the processing plants that were injecting product into the lateral and have them cease pumping.

About 7:07 a.m., the lab technician telephoned from the Brenham area to tell the dispatcher that they had "popped the top" on the cavern. The lab technician told the dispatcher to take HVL product from the cavern and inject it into the mainline. The dispatcher responded that he had G-Grade product (ethane-propane) in the mainline, which was not compatible with the Y-Grade mix that was in the cavern. The lab technician told the dispatcher to go ahead and inject the cavern HVLs into the mainline. The dispatcher again questioned whether the lab technician really wanted to mix the two grades of HVLs. The lab technician, who was not aware that an earlier HAZGAS alarm had shut off all pumps at the station, said to do so.

Time	Alarms Received
6:40:43	Mainline pump pressure alarm
6:41:13	Mainline pump pressure alarm
6:44:19	Mainline pump pressure alarm
6:45:11	Mainline pump pressure alarm
6:45:44	Cavern pump pressure alarm
6:46 +/-	Technician calls dispatcher, tells him that vapor is in the station yard, and asks him to call his (the technician's) supervisor.
6:46:11	Cavern pump pressure alarm
6:48:48	Cavern pump pressure alarm
6:48:59	Cavern pump pressure alarm
6:51:02	Mainline pump pressure alarm
6:53:23	Cavern pump pressure alarm
6:57:31	Cavern pump pressure alarm
6:57:54	Loss of Suction Pressure (LOSP) alarm for Bryan Lateral

Figure 17. Pressure alarms and calls received by dispatcher beginning at 6:40:43 a.m.

The other dispatchers were able to contact personnel at one of the two plants pumping into the Bryan Lateral and have them shut down operations almost immediately. However, when they could not get anyone to answer at the second plant, the dispatcher at the Seminole board became apprehensive that if a plant continued to pump product against a closed valve, the pressure might rupture the lateral, so he reopened the Bryan Lateral. He was not aware that the plant pumps were designed to shut down automatically when the pump pressure increased to 1,550 psig.

Within a few minutes, the operator of the first plant contacted was able to reach someone at the second plant by telephone and have him shut down operations. The dispatcher controlling

the Seminole system was still on the phone with the lab technician when the lab technician told him about the explosions at the station. The dispatcher then typed in a command on his SCADA keyboard trying to re-close the Bryan Lateral valve, but his telemetry system showed that data transmission with Brenham station had ceased.

Dispatcher Work Load.--The dispatcher who had been monitoring Brenham station on the morning of the accident, described his work load in the moments before the explosion as having to handle several tasks in a short period. In enumerating his responsibilities, he listed shutting the Bryan Lateral and the mainline, telling other dispatchers what to do, directing the plants to shut down the lateral, reopening the lateral, and monitoring the SCADA for additional information. In describing the period during which he was attempting to reopen the valve, the dispatcher stated, "While this was going on ... it was ... like I said, chaotic up there." He said that no one from the dispatch center had an opportunity to call the fire department before the explosion; however, he did receive word from the other dispatchers that the fire department had called the dispatch center, although he was not aware of the content of their discussions.

The dispatcher stated that although the technician had called (about 6:46 a.m.) and confirmed that the hazardous gas alarm was real, he had not indicated the seriousness of the situation. The dispatcher added that he "was caught off guard" when the area operator called him at 7:03 a.m. and told him that the cavern was possibly full.

Explanation of Flow Data.--After reviewing recorded pressure and flow data,

Time	Alarm and/or Response
7:03	Area operator calls and advises dispatcher to shut down Bryan Lateral
7:06:04	LOSP alarm for cavern pump
7:06:09	Dispatcher types code to close Bryan Lateral valve
7:06:31	ROC alarm; telemetry system shows rate of flow is 21 bbls/hr
7:06:38	Bryan Lateral valve closed
7:06:49	ROC alarm; flow rate is 3 bbls/hr
7:07 +/-	Lab technician calls to report large mushroom-shaped cloud over the station and directs dispatcher to pump product from cavern to the mainline
7:09:33	Dispatcher types code to open delivery valve to 14-inch mainline
7:10:25	Delivery valve to mainline is open
7:10:46	Dispatcher enters command to open Bryan Lateral
7:11:23	ROC alarm; system shows Bryan Lateral flow is 1,671 bbls/hr
7:11:33	Bryan Lateral valve fully open
7:11:40	ROC alarm; cavern flow out is 1,650 bbls/hr
7:13:57	"XMIT ERROR" on alarm logger

Figure 18. Alarms and actions taken by Seminole board dispatcher before explosions.

a MAPCO spokesperson testified that on April 7, 1992, the following occurred:

Between 3 a.m. and 6 a.m., the cavern was receiving Y-Grade product from the Bryan Lateral at a rate of about 800 barrels an hour. At 6:09 a.m., when the HAZGAS alarm shut the cavern pump down, flow through the cavern meter ceased immediately. As pressure in the Bryan Lateral increased enough to override the pressure in the cavern, flow in the lateral resumed. The resumption of flow was interrupted periodically as pressure equalization occurred. Records indicate that the flow rate through the cavern meter was as follows: 6:15 a.m. - about 400 barrels an hour; 6:30 a.m. - about 850 barrels an hour; 6:45 a.m. - about 1,000 barrels an hour; and 7 a.m. - about 1,000 barrels an hour. After 7 a.m., flow varied substantially when the Bryan Lateral closed; flow in through both the Bryan Lateral and the cavern meters went to zero. About 2 to 3 minutes elapsed, the Bryan Lateral valve was reopened, and flow resumed.

Meteorological Information

Surface data obtained from a Man computer Interactive Data Access System (McIDAS) station box located 26 nautical miles north of Brenham, Texas, showed that at 0700 local time on April 7, 1992, the temperature was 54° F, the dewpoint was 50° F, winds were northerly at a speed of less than 2 knots, and pressure was about 1,018 millibars.

Medical and Pathological Information

A 6-year-old child died from blunt force trauma when the impact of the blast demolished his parent's mobile home. Another resident of the same home suffered serious blunt force trauma and was MEDEVACed by LIFE-FLIGHT from the accident site to the emergency trauma center at Hermann Hospital, Houston, Texas. The three occupants of the vehicle that entered the vapor cloud sustained serious burns and were taken by ambulance to Trinity Medical Center in Brenham, where they were MEDEVACed by LIFE-FLIGHT to the burn center at Hermann Hospital in Houston. Two of the three burn victims died within 5 days of the explosion.

Excluding the 3 burn victims who were transferred to Hermann Hospital, Trinity Medical Center received 17 patients, 2 of whom were admitted. Bellville General Hospital, Bellville, Texas, received 2 patients, both of whom were treated and released. From interviews with paramedics and a survey of area residents, Safety Board investigators determined that dozens of other residents sustained minor injuries, mostly lacerations from broken glass.

Emergency Preparedness

Community Preparedness.--In December 1991, the Texas Department of Public Safety (DPS) approved the Washington County Disaster Plan as meeting all applicable State and Federal requirements. According to the county EMC, Washington County had previously tested its disaster plan by simulating tank truck roll-overs and tank car derailments involving hazardous materials. Before the Brenham station explosion, the county's disaster plan had last been activated in January 1992, when heavy rains caused area flooding.

Under the disaster plan, the county judge (the chief executive officer of Washington County) is responsible for the overall emergency management, planning, and operation. The Washington County EMC is responsible for coordinating the actions of the local government response agencies, including law enforcement, fire, and emergency medical services. The EMC is responsible for activating the emergency operations center, providing emergency information to the public, and, if necessary, arranging for evacuation of the public.

Company Preparedness.--Under 49 CFR 195, pipeline operators are required to:

Develop and follow procedures notifying fire department, police, and other appropriate public officials of hazardous liquid pipeline emergencies, and to coordinate preplanned and actual responses with them during an emergency, including additional precautions necessary for an emergency involving a pipeline system transporting a highly volatile liquid. (195.402 (e)(7))

Establish a continuing educational program to enable the public, appropriate organizations, etc. to recognize and report a hazardous liquid pipeline emergency to the operator, fire department, police, or other appropriate official. (195.440)

In addition to the above regulations, on November 20, 1991, the Research and Special Programs Administration (RSPA) of the U. S. Department of Transportation (DOT) issued an alert notice advising all owners and operators of hazardous liquid pipelines to review their public education programs and consider both elevation and distance from the pipeline in carrying out their public education programs.

The RSPA alert notice was issued in response to the Safety Board's investigation of the March 13, 1990, liquid propane pipeline accident at North Blenheim, New York, in which the Board recognized that existing Federal public education requirements on recognizing and responding to emergencies were inadequate for pipelines that transport HVLs. As a result of the North Blenheim accident findings, the Safety Board recommended that the RSPA:

Require operators of pipelines that transport highly volatile liquids to extend their public education program to include persons who reside at elevations lower than and within 1 mile of the pipeline. (P-91-3)

During a Safety Board hearing on the Brenham explosion, MAPCO officials testified that while they were aware of the RSPA alert notice, they had not taken action to extend the company's public information program beyond owners along the pipeline right-of-way.

Procedural Guidelines.--The MAPCO operating manual contains the following guidelines in regard to emergency procedures:

All Central Dispatch and Field efforts must be directed to securing the area by getting personnel to the leak area to close valves, establish road blocks, evaluate hazards, warn people, and in general, prevent damage to life and property. One company representative capable of evaluating, planning, and coordinating leak site activities must go directly to the leak site and take charge.

The MAPCO's protocol for responding to a hazardous gas alarm required that the individual who received the call-out proceed to the scene and determine the reason for the alarm. If a release had occurred, the respondent was to notify the dispatcher and his (the respondent's) supervisor. If the release was significant, the respondent was to secure the area, warn local residents who might be exposed to the product, and evacuate or blockade the area to ensure that no one entered it. The spokesperson further stated that the Tulsa dispatchers had telephone numbers for the emergency response agencies of each county through which the pipeline crosses.

Public Education.--The emphasis of MAPCO's public education program was to inform owners of property along the pipeline, appropriate Government organizations, and people who might engage in excavation how to recognize a hazardous liquid pipeline emergency and to whom they should report an emergency. MAPCO had a two-part program. For property owners of record, the company annually mailed out packets of information; for local government agencies, the pipeline company provided pamphlets containing its emergency procedures and a master key to unlock valves and gates to facilities; for local response agencies, the company annually conducted periodic emergency response training.

Safety Board investigators determined that MAPCO mailed the information packet to property owners in December. Each packet contained a number of items commonly used about the home and each item prominently displayed the dispatch center's telephone number. For example, the company sent residents a calendar imprinted with emergency response telephone numbers and the suggestion that recipients hang it near their telephones.

Records show that MAPCO last conducted a fire school for response agencies near Brenham station on January 27, 1990. More than 84 firefighters from Washington and Austin Counties and Brenham station field employees attended the school. Participants received information about the station, MAPCO's emergency procedures, and the properties of HVLs that were transported through the station. They were also shown how to inspect and maintain a portable dry chemical fire extinguisher and how to extinguish fires involving small, confined pools of HVLs, fires at leaking flanges, and fires at open pipe ends.

MAPCO also provided local fire departments, sheriffs' departments, and government agencies with an emergency response package. The package included a master key to the station gate and any mainline block valve along the pipeline and a booklet describing the pipeline system, products being transported, how to recognize emergency situations involving the Seminole line, and what actions to take (see figure 19).

Employee Training.--As mentioned previously, MAPCO conducted periodic safety meetings with employees to introduce new information impacting pipeline safety and to review required response procedures to emergency situations. A review of MAPCO's safety meeting agendas shows that, among other emergency response issues, the sessions included discussions of decision-making factors that were involved in establishing road blocks and evacuating endangered residents. These sessions emphasized what actions the first employee arriving at an emergency was expected to take and what information that employee was to obtain, such as location of exposures, ignition sources, and cloud size.

Safety Equipment.--At its Sugar Land office, which was about 87 miles from the Brenham station, MAPCO maintained a "safety trailer" that contained essential emergency response equipment to assist operating crews at remote locations. Equipment included an emergency flare stack, personal protective gear, such as self-contained breathing units and flame retardant coveralls, and repair tools used in emergency operations. Field employees testified that the personnel who conducted the safety meetings advised employees of the availability of the safety gear and described how the equipment was to be used.

1. Call Seminole Pipeline Company dispatcher collect at telephone number (918) 584-4471 Tulsa, Oklahoma.

2. Give dispatcher your location and the location and seriousness of the emergency, especially the size of the vapor cloud.

3. Follow dispatcher's instructions as to closing block valves, checking size of vapor cloud, and evacuating any residents under or in path of cloud. Guard area to avoid ignition if possible.

IF IGNITION HAS OCCURRED, DO NOT ATTEMPT TO PUT OUT FIRE

4. Block roads and keep people out of area.

5. Maintain contact with dispatch until company personnel arrive at the scene.

Figure 19. Response actions listed in Seminole's emergency response material.

Company/Community Coordination.--According to MAPCO's regulatory coordinator, the company did not coordinate with the local emergency response planning groups of communities along its pipeline when it developed its emergency procedures. He also stated that MAPCO had not attempted to determine whether the company's procedures met the training needs of local emergency response groups or whether the company's emergency response plan was consistent with the needs of communities. Before the Brenham accident, the regulatory coordinator had reviewed the MAPCO *Procedural Manual* and found that it did not address normal or emergency operations at unattended stations. The regulatory coordinator said that he brought the matter to the division management's attention and that the division manager said he believed the existing procedures were sufficient and that changes to the manual weren't warranted.

Postaccident Critique.--On May 7, 1992, the Emergency Management Director (EMD) convened a postaccident critique meeting at the Washington County Court House. According to the EMC, all Washington and Austin County public agencies that responded to the accident were invited to participate in the critique. Austin County agencies did not attend. The participants identified the following problems:

Communications.--Heavy radio and telephone traffic and loss of lines hampered communications. The explosion knocked out many telephone lines within several miles of the station. In addition, area residents trying to report injuries and damage and/or trying to determine the origin of the explosion jammed the 911 number with calls. A telephone company spokesperson reported that more than 31,000 calls were made to the area exchange during the first hour following the blasts. Responders stated that phone problems caused some confusion, miscommunication, and delay. Information could be relayed only by radio. According to the EMC/EMS director, because all responders were trying to use the same radio channels, "...you just got in [on the radio channel] when you could."

Product information.--The EMC stated that he "didn't know what kind of gas we were dealing with." He said that an on-site fireman told him it was methanol gas.²⁰ He said that he did not talk to any pipeline representative until 11 p.m., nearly 16 hours after the accident, when two pipeline employees came to the command post. The Brenham fire department chief stated that when he was on the station site, he had talked with pipeline employees and determined that the fires burning posed no danger. From postaccident interviews, Safety Board investigators determined that the fire chief neither relayed necessary information to the EMC nor requested that MAPCO provide a technical person at the command post. The EMC said that if he had to do it over again, he would immediately evacuate the whole 10-square-mile area because of the potential danger to rescue personnel and possibility of flammable gas in the area.

Access.--The primary road to the station, CR 19, is a narrow gravel road. The force of the explosions snapped and leveled trees surrounding the station and disabled the fire victims'

²⁰ The fireman reportedly had seen "methanol" painted on an above-ground tank at Brenham station and concluded that it was the product with which responders were dealing.

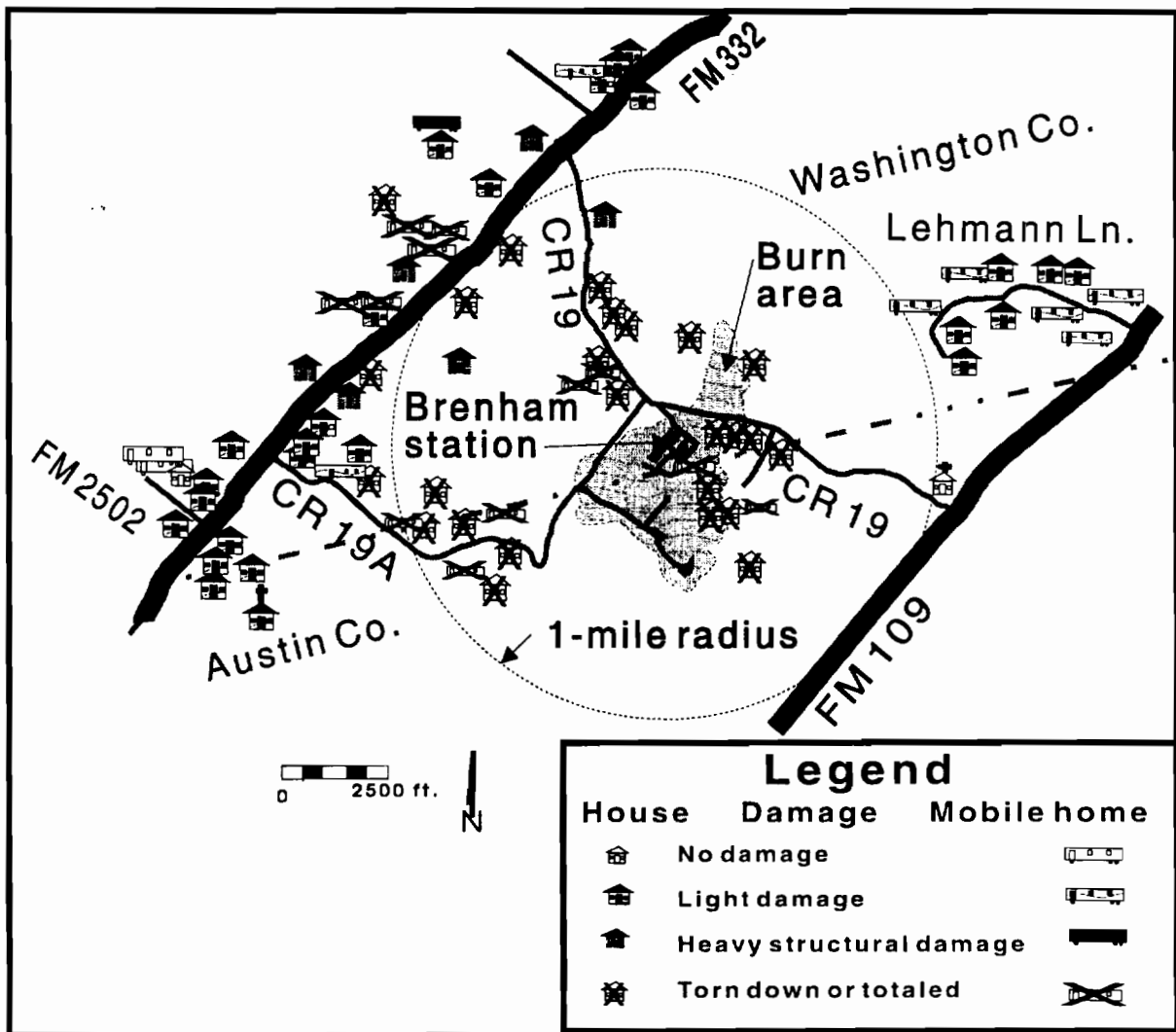


Figure 20. Damage to homes and structures near accident site.

car and the Seminole truck at the station entry road, which made CR 19 impassable. First responders to the scene had to radio follow-up units to reroute to FM 109. Response agency officials added that when it became evident to volunteer responders who had been placed on alert that phone lines were out or inoperative, many decided to proceed to the scene, increasing the potential for gridlock on the roads to the station. Although Department of Public Safety (DPS) personnel later blocked all access to CR 19, response personnel, residents, news media representatives, and clean-up crews, believing that the area posed no danger, moved freely on CR 19 after the explosions.

Training.--The EMC stated that he was not familiar with MAPCO procedures and had not participated in any pipeline-sponsored training held in the county. The Safety Board determined from interviews that when he had assumed the job several years earlier, Washington County had not provided the current EMC with any information about Brenham station or MAPCO's emergency response booklet.

Tests and Research

Gas Analysis.--On April 10, Safety Board investigators documented the pressure at the cavern wellhead as 440 psig in the brine tube and 420 psig in the product pipe. They also found that product filled the brine tube. Investigators removed an HVL sample from the brine pipeline above the wellhead and sent it to a private laboratory for analysis. Tests showed the HVL to be composed by weight primarily of propane (32.92 percent), ethane (32.51 percent), n-Butane (14.11 percent), n-Pentane (4.40 percent), Isopentane (4.30 percent), and n-Hexane (1.08 percent). Laboratory technicians also identified 38 other materials, including methane, none of which comprised more than 1 percent of the total sample weight (see appendix B). The weight percentages of the identified components approximated the HVL mix in the April 6 deliveries.

Cavern Test.--On May 26, 1992, MAPCO contracted a well-survey company to perform a sonar measurement of the cavern to determine its size and capacity. The survey, which was attended by Safety Board investigators, showed that the top of the cavern was 2,728 feet below ground and that the bottom of the cavern was 2,875.3 feet below ground. The approximate capacity of the cavern was 380,000 barrels.

To obtain a more accurate accounting of the amount of HVLs in the cavern, the Texas Railroad Commission recommended and MAPCO agreed to remove all product from the storage facility by means of displacement. A Commission representative monitored removal of the product, which occurred between July 8 and August 16, 1992. Tests of the brine in the ponds showed that it was not fully saturated with sodium chloride. Because the ponds did not contain sufficient brine to displace all of the product, MAPCO had to inject fresh water into the cavern. The volumes and salinities of the brine and the water used to empty the cavern were measured. A total of 338,995 barrels of HVLs were removed from the cavern, about 51,000 barrels more than the 288,305 barrels indicated in company records. A small, undetermined amount that remained in the cavern was released and flared.

When questioned about the almost 51,000 barrels of extra product that was in the cavern on April 7, 1992, the company executive officer stated that the way these caverns operate, there are several ways to have too much or too little product. He testified, "Just the accuracy of the measurement system itself in the volume of the product that goes through the cavern, simple multiplication, can give you some pretty wide areas in the volume that could be in the cavern."

On September 30 and on October 2, 1992, MAPCO contracted two other companies to do additional sonar surveys of the cavern to document the growth of the cavern after the accident. Calculated cavern capacity from the first survey was 384,925 barrels, a 1 percent variance from the May 1992 survey. Calculated capacity from the second survey was 356,965, a 7 percent variance from the May 1992 survey. As a consequence of these surveys, MAPCO found that the lower end of the 13 3/8-inch-diameter pipe was 2,702 feet below the wellhead, rather than 2,728 feet as indicated in the May 1992 survey.

Pumps.--In the process of inspecting and overhauling both cavern pumps, MAPCO found that the electric motors of the pumps were heavily damaged in the explosion, but that the pumps themselves were not damaged. Internal inspection of the pumps showed no damage from cavitation²¹ or other causes; the impellers were not damaged and the casings contained no defects. Records showed that the pumps had no previous cavitation damage.

Metallurgy.--Investigators removed several system components from the accident scene and sent them to the Safety Board's laboratory in Washington, D.C., for metallurgical examination (see appendix B).

Coastline's 6-inch riser and associated components.--Investigators had a section of the carrier's 6-inch-diameter riser removed from Coastline's area that had been enclosed by chain link fence before the explosion. Only three of the four 1/2-inch pipe connections to the riser still were attached. The fourth 1/2-inch pipe connection was found partially imbedded in the ground about 47 feet from where the fence enclosure had been. Safety Board investigators also submitted this component to the lab for examination. Analysts determined that the soot deposits on the riser were consistent with exposure to a fire and that the deformation of the piping components resulted from bending load and not a pre-existing condition. Evidence also indicated that damage to the Coastline riser and associated components resulted from the enclosure fencing being blown onto the riser.

Overpressure sensing equipment.--Safety Board investigators also submitted for laboratory examination components that comprised the pressure sensing line between the brine ponds and the storage cavern. Safety Board metallurgists examined the pressure sensing tubing, fittings, two manual valves in the sensing line, the electric solenoid valve used to release the cavern safety valve, and the Barksdale pressure switch. Evidence indicated that damage to the tubings and fittings resulted from excessive loads and not from pre-existing conditions. An X-ray of the manual valve on the pressure sensing tubing and tests on its handle indicated that the valve was in the closed position when its handle separated from it.

Initial tests of the Barksdale switch were inconclusive. The Safety Board therefore arranged for the engineering department of Barksdale Controls, the manufacturer of the switch, to conduct additional tests at its laboratory in Los Angeles, California. A Safety Board investigator hand-carried the device to Barksdale for testing. Tests and examinations specified by the Safety Board were conducted in the presence of the parties to the Brenham investigation. Barksdale engineers tested the switch components and concluded that the set screws in the pressure fittings had been loosened and retightened because the screws were not to the manufacturer's torque specifications. They also found that the original bourdon tube sensing element and the switch housing had been replaced.

²¹ Cavitation is the formation of partial vacuums within a liquid. The collapse of the partial vacuums causes pitting or other damage to the metal surface that is in contact with the liquid.

The Barksdale engineers next conducted pressure tests of the micro switch. They applied nitrogen under pressure in 10 psig increments up to 200 psig and the micro switch failed to actuate. When engineers tried to change the pressure setting on the switch and could not turn the adjustment screw, they found that the adjustment screw was corroded and frozen in its bore.²² Microscopic examination showed that both the inlet and outlet ports of the surge damper were blocked by a mixture of salt, rust, pipe scale, and sand. After removing the blocked surge damper, the engineers pressure tested the switch again and it tripped as designed. Based on visual examination of the switch components, the engineers concluded that the metal switch housing had been disassembled and reassembled in the field.

Fusible link.--Safety Board investigators submitted the separated half of a fusible link that was connected to the cavern safety valve chain and exemplar fusible links of the same design for laboratory examination. Safety Board laboratory personnel determined that the components showed no evidence of bending or twisting deformations and that the link had separated as a result of excessive temperature.

Explosion Modeling Calculations.--To estimate how much product had been released at Brenham station, the Safety Board used a computer program to model product release and explosion scenarios. Calculations were based on eyewitness accounts of the height of the vapor cloud, the size of the burned area, and assumptions that the gas vapor cloud was uniformly mixed and dispersed over the station area.

Pipeline employees who were on scene before the explosion testified that the vapor cloud was above tree-top level (20 to 30 feet), mushroom-shaped, and covered the entire station area. Three employees observed the column of liquid at brine pond No. 1 from different vantage points. The technician trainee, who was standing near the culvert of the entry road, saw "fluid rising about 10 feet" above the brine pond embankment. The pipeliner, who walked several feet farther up the entry road to a point just past the culvert, described a column shooting up "about 50 feet ... from the area of the brine discharge line in the corner of the pit." From his vantage point immediately south of the intersection of Glory Lane and CR 19, the area operator also observed "a column shooting up." The lab technician, who was in his truck en route to the station and was about 2 1/2 to 3 air miles from the scene, described a mushroom cloud "with a pointed top."

The Safety Board analyst used the observations of on-scene employees to develop two vapor cloud scenarios. Calculations in the first scenario were based on the average molecular

²² When they removed the Barksdale switch at the accident site during the postaccident on-scene examination, Safety Board investigators noted that the cap that covered the adjustment screw was missing.

weight of the product mix;²³ calculations in the second scenario were based on the partial pressures of the products in the mix.

The burn area (see figure 20) at the accident site measured almost 8 million square feet. The Safety Board determined that about 78 barrels of product would have to be released to produce a 1-foot-high propane vapor cloud of 2 percent concentration, the lower flammability limit (LFL) of propane, that would cover an area the size of the burn area. About 7,020 barrels of propane product would produce a 20-foot cloud of 9 percent concentration, the upper flammability limit (UFL) of propane. Calculated amounts based on ethane were even higher. To produce a 1-foot-high ethane vapor cloud of 3 percent concentration, the LFL of ethane, about 167 barrels of product would have to be released. About 11,136 barrels of ethane product would produce a 20-foot cloud of 10 percent concentration, the UFL of ethane.

The Safety Board also ran a computer model to determine the impact of explosive forces on structures (excluding mobile homes) at various distances from the assumed point of ignition. The explosion efficiency factor of an unconfined vapor cloud is low, only about 3 percent of the heat of combustion.²⁴ When the Board used a yield efficiency factor that was almost 4 times the expected efficiency and an average product release amount of 1,380 barrels, the model did not produce an explosive force equivalent to the actual on-scene structural damages observed.

Based on the divergence between the damage modeling statistics and actual damage and the descriptions of the cloud height, the Safety Board analyst concluded that at least 3,000 barrels and possibly as many as 10,000 barrels of product were released at Brenham station. The lack of uniformity in damage at similar distances from the point of origin supported the finding that multiple explosions occurred.

From its analysis, the Safety Board found that the following scenario most realistically supports the finding that multiple explosions occurred and extensive structural damage occurred well beyond the visible vapor cloud that covered Brenham station: A hydrocarbon mix vapor cloud spread over the landscape. The wind velocity was very low, which allowed the components having a higher molecular weight and lower vapor pressure, such as butanes, pentanes, and propane, to spread along the ground, while the lighter-weight ethane constituted the upper part of the vapor cloud. The hydrocarbons along the ground were subject to low-level ignition. Most likely the low-level components were ignited first, in turn igniting the higher vapor cloud of ethane. The explosion of ethane at a relatively high elevation may have ignited higher molecular weight components that had accumulated in other low-lying areas. This scenario explains the destructive forces that were not symmetrical around the epicenter of the explosion.

²³ The computer program used could not perform calculations based on a mixed product. The Safety Board therefore first calculated release amounts using a liquid product that was 100 percent propane and then a product that was 100 percent ethane. The molecular weight of the actual product mix was almost equal to the weight of propane, the second most abundant product in the mixture.

²⁴ D. Daniels and R. Albery, *Physical Chemistry*, John Wiley & Sons (1955), pp. 113-114.

Prior Releases from Brenham Station.--A MAPCO technician who was at Brenham in 1982 stated in an affidavit that he recalled that "A product escaped from the cavern via the brine line [tube] and into the pit [pond]." The technician said that he believed that the release was on March 18, 1982, and recalled that he and the lab technician manually closed the cavern safety valve. He later determined that the Barksdale switch had activated and that the Tulsa dispatch office had received a signal indicating the Barksdale had activated. He tested the Barksdale switch and found that it did transmit a signal to the solenoid, but that the solenoid failed to release the cavern safety valve. He found the coil in the solenoid burned out, which rendered the release mechanism inoperative.

The lab technician, who has worked at Brenham since 1981, stated that he was aware of two previous incidents involving the cavern. In fall 1982, he was in the control building when he received a call from the division office at Sugar Land advising him of a HAZGAS alarm, which he believed had been received at the Tulsa dispatch center. From the door of the control building, he saw a column of water being sprayed about 20 to 30 feet above the berm of the brine pond.²⁵ He recognized the event as a disturbance in the cavern and went to the wellhead, where he closed a manual valve on the brine tube. MAPCO has no record of this incident.

The lab technician said that in spring 1988, he was walking along the top of pond No. 1 when he observed bubbling within the brine. He said that neither the HAZGAS detectors nor the cavern valve had activated and that he closed the manual valve. However, SCADA records show that in February 1988, the dispatch center received several HAZGAS alarms from Brenham station and that the Barksdale switch had activated in most instances. MAPCO shut the cavern down, removed the cavern brine tube, and, after examination, replaced it. The company's report of inspection shows that several corrosion holes were found at pipe connections in the brine tube. A company spokesperson said that after the incident, a technician cleaned and checked the Barksdale switch and returned it to service.

Federal, State, and Industry Oversight

Office of Pipeline Safety (OPS)--The OPS is part of the U.S. Department of Transportation's Research and Special Programs Administration (RSPA). Its representative testified that the OPS is responsible for issuing and enforcing safety regulations affecting the pipeline transportation of both liquids and gases. Section 205(a) of Public Law 102-508 provides that the OPS may allow a State agency to participate in the safety regulatory effort for intrastate liquid pipelines. The State agency becomes the primary inspection and enforcement agency when it certifies to the OPS that it has adopted all applicable Federal pipeline safety requirements, that it has staff qualified to inspect pipeline operations and determine whether they conform to the safety standards, and that it will take action against nonconforming operations as necessary. The

²⁵ In 1982, Brenham station had one brine pond. The original pond is now pond No. 1.

State agency can also impose on intrastate operations safety requirements more stringent than the Federal requirements. For a State agency to maintain its certification, it must submit to an annual OPS inspection of its operations.

The OPS certified the Transportation/Gas Utilities Division of the TRC as the Texas agency responsible for the safety of intrastate liquid pipeline operations and has annually inspected and found acceptable its pipeline safety regulations, inspection of intrastate pipeline operations, and safety enforcement actions. The OPS representative characterized that agency's operations as "fully adequate and we think it's one of the better programs of the States."

The OPS Associate Administrator of Pipeline Safety advised the Safety Board on June 11, 1992, that the OPS has not issued safety requirements on underground storage of hazardous liquids and natural gas even though both the Natural Gas Pipeline Safety Act and the Hazardous Liquid Pipeline Safety Act give it that authority. The OPS administrator advised the Board that historically, the OPS views the end point of its regulations and inspections as the last valve on the wellhead through which gas or hazardous liquid enters storage.

The OPS representative at the Safety Board's hearing explained that the Federal pipeline safety standards initially developed by OPS were based on then-available industry standards (American National Standards Institute's B31.4 and B31.8 on liquid and gas pipelines, respectively), which did not address underground storage. Since issuing the initial Federal pipeline safety standards, the OPS has taken no action to address the safety of underground storage systems. The OPS representative said that even though the OPS had not developed requirements on underground storage, State agencies were not barred from developing such safety requirements and that the OPS was aware of a few State agencies that do regulate storage in geologic formations.

The OPS representative said that since the Brenham accident, the OPS has begun to collect information on the number and type of underground storage systems used in pipeline transportation, to review various sources of statistics that would assist in determining the numbers of releases of gases and liquids that occur annually, and to consider the actions that the OPS might take on gas and liquid underground storage systems. He said that the OPS was aware that many underground storage systems would not be subject to the safety standards it may issue because they would not be considered part of pipeline transportation. This would include underground storage systems for gases and liquids at transportation terminals, refineries, and chemical plants where the materials stored would not involve further pipeline transportation.

Texas Railroad Commission (TRC)--Responsibility for the safety of the Seminole pipeline system operations within the TRC was divided between the agency's Oil and Gas (O&G) Division and its Transportation/Gas Utilities (GU) Division. The GU division is responsible for pipeline operations, and the O&G division is responsible for underground hydrocarbon storage operations.

On August 10, 1981, the O&G division issued Seminole a permit to leach a 150,000-barrel capacity cavern and to store HVLs in the salt dome of Brenham Field, about 8 miles southwest of Brenham, Texas. The underground cavern was to be used to store mixed HVLs received from the Bryan Lateral when pure HVLs were being transported through the 14-inch mainline. This would prevent undue contamination of the pure HVLs and avoid expensive refractionization.²⁶ In support of the permit, the company's drilling engineer testified that in constructing the cavern, operations would be conducted to protect all water of useable quality and any oil and gas reserves, that two separate casings would be installed into the salt and cemented to the surface to prevent an escape of HVLs such as the one that occurred at Mont Belvieu, Texas, caverns, which only had one casing; and that the cavern storage facility would be operated at 0.56 psi pressure for each foot of depth. The permit conditions did not address wellhead safety equipment or the manner in which the cavern was to be operated and maintained to minimize the potential for HVL releases.

An O&G representative testified that the TRC considers that its jurisdiction over cavern storage systems begins at the outlet side of the injection pipe and continues toward the storage facility but does not include the wellhead safety equipment. Statewide Rule 74 addresses the safety requirements for the 582 natural gas and liquid underground storage systems subject to the O&G division's jurisdiction (440 are active).

Adopted in 1982, Rule 74 was enacted to meet the requirements of the Federal Safe Drinking Water Act, the purpose of which is to protect underground sources of drinking water. Anyone proposing to construct and operate an underground storage facility is required to file a permit request that includes the following information: nature of the proposed operation, proposed size, type of product to be stored, site geology, proposed facility construction procedures, type and location of active and inactive area wells (including the manner of closure if no longer active), and proof that the required notice has been given to the public. However, those previously granted permits have grandfather rights and do not have to reapply for a permit.

Although not specifically stated in the rule, the O&G division maintains that when Rule 74 became effective, it mandated that operators of underground storage facilities comply with the periodic testing and reporting requirements. Like its predecessors, Rule 74 does not include requirements for wellhead safety equipment or the manner in which the storage facility is to be operated and maintained. However, the rule does require that operators conduct periodic cavern pressure tests to prove structural soundness and report any detected leakage.

Based on hearings held as a result of several identified problems, on November 2, 1986, the O&G division adopted special safety requirements for the underground hydrocarbon storage caverns in the Barbers Hill Field, which is in Chambers County and adjacent to Mont Belvieu. The requirements addressed the use, design, and location of emergency shutdown valves; the notification of public and local officials of emergency agencies; fire prevention and response

²⁶ A process used to separate mixed HVLs into pure components, such as propane.

planning, including details about in-place fire suppression systems; contingency plans to address each potential emergency that might endanger public health and safety; employee safety training, including an annual drill of the emergency plan; and requirements for training contractors and their employees.

On April 15, 1991, the O&G division developed additional requirements for underground storage operations at Barbers Hill Field. All new storage facilities had to have at least two cemented concentric strings of casing through all strata between the salt and the surface. The O&G also stipulated that facilities had to be drilled at least 400 feet from any residential dwelling and at least 100 feet from any street, road, or highway in the city of Mont Belvieu.

A representative of the GU division testified that it has adopted the Federal natural gas and liquid pipeline safety requirements, as well as more stringent requirements of its own for intrastate pipeline operations in Texas. None of these requirements are applicable to underground storage facilities because the division's jurisdiction stops at the outlet of the storage injection pumps. The GU representative explained that this means that neither the TRC nor the RSPA has established standards on safety control equipment at the cavern wellhead, on the pipe between the cavern pump outlet and the cavern injection pipe outlet, and on the hazard detection and control systems needed to ensure public safety when operating an underground natural gas or HVL storage system integrally with a pipeline system. Those omissions are being reviewed by both TRC divisions.

State Regulation of Gas and Liquid Underground Storage.--During the investigation of this accident, the Safety Board sought to identify the number and location of natural gas and liquid underground storage facilities in the States and to determine what public safety requirements existed. The Board could find no single association or agency able to provide the desired information about these facilities. Consequently, the Safety Board asked that the States and several industry associations provide information on the number and location of underground storage facilities. The Board also asked that the States submit copies of their regulations governing underground storage facilities.

The Safety Board received information from 32 States, of which 17 reported having underground storage facilities. Of the 17, only 3 reported having public safety standards on HVL underground storage and only 4 reported having standards on natural gas underground storage. Five additional States reported that they require storage permits, the primary purpose of which is to protect ground water and/or to generate revenue for the State. The Board reviewed permit provisions on pressure tests of underground reservoirs and found that they provided some public safety benefits.

The Gas Processors Association provided the Safety Board with information that it had

on locations of liquid underground storage facilities and the American Gas Association (AGA)²⁷ provided data on natural gas underground storage facilities. Figure 19 shows by State the number and location of underground storage facilities as compiled from all sources. These data indicate that about 1,400 liquid and more than 400 natural gas underground storage facilities are in the contiguous United States; none are in Alaska or Hawaii.

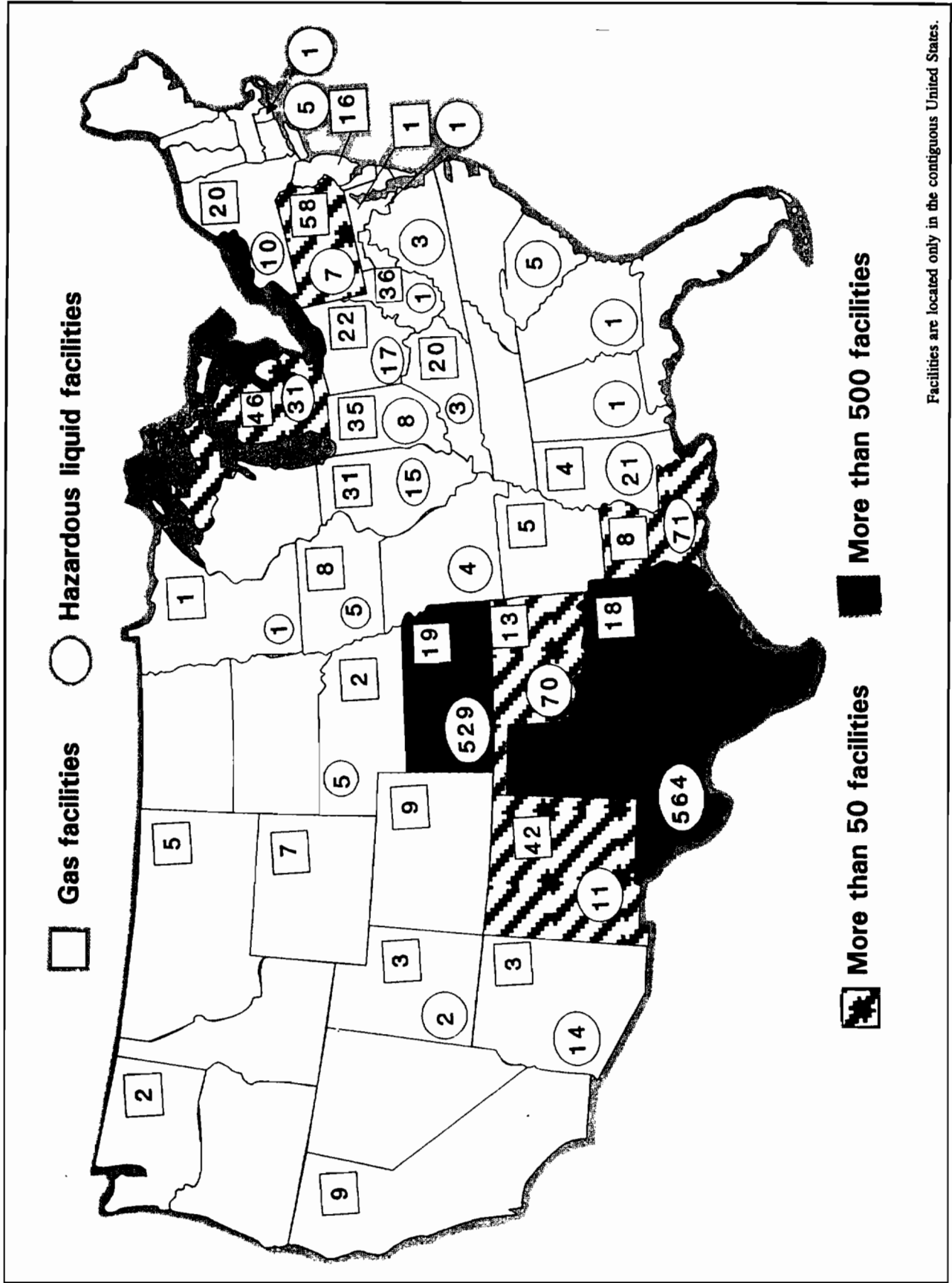
Through discussions with State agency and industry association staffs regarding how operators use these storage facilities, the Board determined that Federal requirements classify most as end point (terminal) storage facilities, where the liquid or gas is transferred from one type of transportation facility to another. Other uses include storage by gas distribution operators to handle peak customer demands during cold weather, storage by industry to handle peak demand fuel for heating and electric generation, and storage by chemical manufacturing industry for feed stock supplies.

Pipeline Industry Associations.--The Safety Board searched recommended practices and guidelines of several pipeline-related organizations to determine what guidance had been provided by industry associations on the design, construction, operation, and emergency preparedness of underground storage systems. Section 6 of the Gas Processors Suppliers Association's (GPSA's) *Engineering Data Book, 1987 Edition*, contains information on underground storage facilities, but not enough technical information to design or operate an underground storage facility. The book advises that underground storage is most advantageous when storing large volumes and identifies underground storage facilities as constructed and converted. Constructed underground facilities include solution-mined salt caverns, conventional-mined salt caverns, and conventional-mined nonporous rock facilities. Converted facilities include depleted coal, limestone, or salt mines. The book states that the GPSA knows of no standard procedures for storing HVLs underground in conventionally mined or solution caverns.

At its July 1992 public hearing, the Safety Board asked the American Petroleum Institute (API)²⁸ and the AGA what assistance they provided their members on underground storage. The API witness said that since 1981, it has recognized the need to develop standards for solution-mined underground storage facilities. Its transportation committee appointed a task force that began developing standards for solution-mined storage facilities, but the task force halted work because of an industry economic downturn. In December 1989, the task force resumed working on standards for design and construction, and in July 1990, resumed working on standards for operations and maintenance. According to a spokesperson, a draft of the design and construction standards includes recommended practices on designer qualifications, cavern design parameters and criteria, wellhead safety equipment, cavern drilling and completion, cavern integrity testing,

²⁷ The AGA is a trade association comprising gas distribution, gathering, and transmission companies and related industries that represent the interests of the domestic natural gas industry before government and the public.

²⁸ The API, a trade association representing the domestic petroleum industry, promotes the interests of the industry, encourages development of petroleum technology, cooperates with the government in matters of national concern, and provides information to government and the general public on matters affecting the petroleum industry.



Facilities are located only in the contiguous United States.

Figure 21. Number of underground gas and hazardous liquid facilities by State.

cavern product inventory measurement, cavern operation, and cavern abandonment. The API expects that both sets of standards will be issued by the end of 1993.

The AGA representative said that underground storage systems for natural gas have existed since 1916 and that they differ in several respects from systems for liquids. Natural gas is a lighter-than-air material that will rapidly dissipate into the atmosphere without posing a hazard to adjacent lower-lying areas, and it will not develop a vapor cloud and cannot detonate in the atmosphere. Underground facilities used to store natural gas are also different; about 85 percent of all storage is in depleted oil reservoirs, 13 percent in natural geologic structures such as aquifers, and 2 percent in salt caverns and an abandoned coal mine. Gas storage facilities are closed systems having no avenue to the surface, such as a brine tube, for product to escape.

The AGA witness stated that present standards applicable to underground natural gas storage were developed for the exploration and production of oil and gas. The API, the American National Standards Institute, and the International Association of Drilling Contractors have recommended practices on wellhead equipment, casing equipment, and drilling operations. The GPSA also has some educational and descriptive materials on underground storage.

The AGA witness identified those agencies having some safety control over underground storage of natural gas. A company proposing to build a system must first obtain a permit. For interstate operations, the Federal Energy Regulatory Commission (FERC) reviews the environmental studies, the construction, and the design proposals for the facility. For intrastate operations, a State agency, such as a utility regulatory commission, performs reviews similar to FERC's. The AGA witness stated that RSPA regulates all piping associated with underground storage facilities because storage is defined in the Federal gas pipeline safety standards as a gas transmission function. In most cases, the States regulate the performance of wellhead and down hole equipment.

While the AGA does not develop standards, the association has an underground storage committee that reviews and disseminates to its members technical information on the safe and efficient operation of both cavern and aquifer storage facilities. The committee works with standard-writing bodies by reviewing and recommending improvements; maintains technical papers; meets biannually to exchange technical information, to review research, and to review environmental regulatory requirements; and collects and publishes statistics on underground storage operations. Recently, the committee reviewed and proposed changes to the API's draft recommended practices on solution-mined caverns.

The AGA representative advised the Board about an affiliate of the Society of Petroleum Engineers (Society), the Midwest Gas Storage Mutual Aid Group, which assists member companies by providing lists of companies and sites having available emergency equipment that a storage operator can obtain rapidly in the event of an emergency. Another Society affiliate, the Appalachian Gas Storage Mutual Aid Group is now forming a similar mutual aid operation in Pennsylvania and adjacent States. The Safety Board is not aware of any similar actions within

the pipeline industry.

Accidents Involving Gas and Liquid Underground Storage Facilities.--The Safety Board developed the following table on underground storage accidents using information from witness statements at the Safety Board's July 1992 public hearing in Austin, Texas, and from prior accident investigations. The table is provided only to show the consequences of some accidents at underground storage facilities. Because it was compiled from limited sources, the table should not be considered a representative sample. Neither the AGA nor the OPS provided detailed data on natural gas underground storage system accidents. The AGA representative stated that she had identified 20 accidents involving natural gas underground storage facilities from member discussions. She added that 10 of the 20 met OPS's requirements on reporting. The OPS spokesman stated that his agency does not require that underground storage accidents be reported to it; the incidents of which he was aware came from a variety of sources, including pipeline operators when damages to regulated pipeline facilities met or exceeded reporting requirements.

Date of Accident	Place of Accident	Company Involved	Details of Accident
Jan 23, 1975	Iowa City, Iowa	Mid-America Pipeline Company	A chiller used to cool the HVL before storage failed, releasing HVLs that ignited and killed two employees.
Mar 29, 1987	Clarmin, Illinois	Illinois Power Corporation.	Soil movement damaged the casing on a storage well, resulting in the release of natural gas. No injuries or deaths resulted.
April 1987	Iowa City, Iowa	Mid-America Pipeline Company.	A flexible pipe on a compressor failed, causing the release of HVLs that ignited. As a result, a relief valve failed in the open position, which released over a period of about 60 days all HVLs in the underground storage cavern. No injuries or deaths resulted.
Dec 5, 1987	Lewis County, West Virginia	Equitable Gas Company	An oxy-acetylene weld on an 8-inch-diameter gas storage field pipeline failed, releasing natural gas. No injuries or deaths resulted.
Jun 23, 1989	McPherson, Kansas	Mid-America Pipeline Company	Cavern overfilled, possibly due to operator error, and HVLs released to the brine pond ignited. No injuries or deaths resulted.
Nov 16, 1989	Carthage, Missouri	Williams Pipeline Company.	Cavern overfill resulted in the release of propane that ignited. No injuries or deaths resulted.
Dec 18, 1990	Navajo Dam, New Mexico	El Paso Natural Gas Company	A 1/2-inch-diameter fuel line to a dehydrator failed, releasing natural gas, which ignited. No injuries or deaths resulted.

Table 3. Underground storage accidents discussed at Austin hearing.

ANALYSIS

This analysis is divided into three main sections. In the first part, the Safety Board identifies station components that can be readily excluded as potential sources of product release. In the second part, "The Accident," the Board describes how the HVL product was released. In the third part, the Board discusses the safety issues identified in the following areas and the findings that support each issue: safety control systems; cavern management procedures; employee and management performance; and Federal and State safety requirements and oversight for underground storage and related pipelines.

Exclusions

The Safety Board excluded the following as sources through which the HVLs escaped:

Seminole's 14-inch Mainline and Station Piping.--After minor repairs were made to fittings damaged by the explosion, pressure tests showed that the mainline and station piping did not leak.

Coastline Piping.--Because escaping product from Coastline's above-ground piping was on fire after the explosion, investigators considered the Coastline riser a potential source of the initial HVL release. Laboratory examination revealed that damage to Coastline's pipe had resulted from external impact, specifically when the surface blast hurled the chain-link enclosure fencing onto the aboveground 6-inch piping, fracturing, cracking, and deforming the 1/2-inch pipes attached to the 6-inch piping.

Other factors support the finding that Coastline's piping was not the initial source of product release. Specifically, before the hazardous gas alarm and up to the time of the explosion, neither Seminole's nor Coastline's telemetry data system showed a pressure drop in the Coastline pipeline that was inconsistent with the change in temperature.

Cavern Structures.--Pressure tests taken after the accident showed that the reading at the cavern wellhead was 440 psig and holding and that the cavern showed no evidence of product leakage. Subsequent pressure and mechanical integrity tests indicated that the cavern walls, piping, and seals were structurally sound and did not leak.

Based on postaccident inspections and laboratory tests, the Safety Board concludes that product was not released from the mainline and station piping, the Coastline piping, or the cavern piping or structure.

The Accident

Pressure graphs show that the computer outage that occurred about 3:45 a.m. at the dispatch center had no impact on operations and that readings from Brenham station were normal until shortly before 6 a.m. At that time, the cavern pump discharge pressure began decreasing, while the pump suction pressure remained constant (see figure 16). The Safety Board believes that the reduction in the pump discharge occurred when product began to enter the weep hole and brine in the brine tube began to be displaced. Because a downstream control valve was regulating the pump suction pressure, that pressure remained constant at this time. As more HVLs entered the brine tube and mixed with the brine, the specific gravity of the brine was lowered, causing less pressure to be applied to the product in the cavern.

Because HVLs have a specific gravity about half that of brine, the product entering the brine tube rose high enough in the brine tube that the pressure was insufficient to maintain some of the Y-Grade HVLs in a liquid state (calculations indicate that some of the liquids would change to vapor beginning about 1,000 feet below the surface). Some of the HVLs in the Y-Grade mix then changed into vapor and rapidly expanded, increasing the space that they occupied within the brine tube and displacing more brine. As more HVLs formed vapor, more brine was displaced, causing a further decrease in the pressure exerted on product within the cavern.

The HVL vapors rose through the brine tube and were released to the atmosphere through the brine ponds. When a concentration of HVL vapors sufficient to activate the station's gas detectors reached one or more of them, the HAZGAS alarm at the dispatch center was activated, and the station's pump shut-down system shut down the cavern pump. This caused a temporary cessation of HVL flow into the cavern and initiated a rapid increase in the cavern pump suction pressure and in the Bryan Lateral pressure because the plants were still pumping Y-Grade HVLs into the lateral. (Refer to 6:10 a.m. entry on figure 16).

The Brenham cavern shut-down system was not designed to automatically close key valves, including incoming and outgoing pipeline valves and the cavern valve. Thus, the flow into the cavern resumed even though the pump had shut down because the Bryan Lateral pressure kept the pressure at the pump above that needed to allow HVLs to enter the cavern. The Bryan Lateral pressure continued to increase while the cavern flow rate was less than the rate at which HVLs were being pumped into the Bryan Lateral by the plants. Because HVLs entering the tube through the weep hole were displacing brine, the rate of HVLs entering the cavern increased as the Bryan Lateral pressure increased and as the pressure exerted by the weight of the brine in the tube decreased.

Meanwhile, the dispatcher monitored the changing pressure and flow rate readings on his screen, but did not interpret them as constituting an emergency. The Safety Board believes the dispatcher failed to recognize the changing pressures in the station piping because his training on recognizing emergencies did not include emergencies occurring in station environments. Moreover, the computer did not provide a graphic display of historic data, which would have

him to see pressure and flow rate trends, he was unable to identify the meaning of the numerous changes that were occurring.

So much HVL entered the brine line that the brine was displaced, allowing the HVLs nearing the bottom of the brine tube to flow directly into the tube. The Safety Board cannot determine precisely when this occurred because cavern and brine tube pressures were not recorded. However, figure 16 shows that the pressure at the pump was high enough (more than 790 psig) to allow the flow into the cavern to continue for about 20 minutes after the cavern pump shut down. By 6:30 a.m., pump pressure was too low for flow to continue under normal conditions. Nonetheless, flow did continue because pressure in the brine tube had been reduced by the infusion of HVLs through the weep hole; thus, less pressure was needed to flow HVLs into the cavern.

As reflected in figure 16, the pressure in the Bryan Lateral continued to build until about 6:35 or 6:40 a.m., an indication that the volume of HVLs flowing into the cavern was smaller than the volume of HVLs flowing from the plants into the lateral. These conditions further indicate that the HVL level had not yet reached the bottom of the brine tube. The curves show that the Bryan Lateral pressure began to decrease and product flow rate into the cavern increased, attaining flow rates higher than when the product was being pumped. The Safety Board concludes that soon after 6:40 a.m., HVLs began to flow from the cavern through the bottom of the brine tube, limited only by the tube's size and frictional characteristics.

After the explosion and during subsequent inspections, two manual valves in the sensing line were found closed. Had both valves been open at the time of the explosion, any one of several pipeline company employees who were at the wellhead soon after the explosion would have observed either a fire burning at the brine pressure sensing pipe, which explosive forces disconnected, or the escape of HVL vapors from the disconnected sensing line. Because no employee reported seeing either, the Safety Board concludes that one or both manual valves in the brine sensing line were in the closed position when the expansion of HVL vapor increased the pressure in the brine tube. Because the valves in the sensing line were closed, the Barksdale switch did not activate to close the cavern's safety valve. The last time that either manual valve would have been closed as a matter of routine was during a March 1992 maintenance test. However, sufficient information does not exist to conclude that either valve was left closed at that time.

Despite the cavern being overfilled, no substantial quantity of HVLs would have been released had the wellhead safety system been operative. The Safety Board concludes that HVLs were released from an overfilled underground storage cavern because Seminole's wellhead safety system, which was not equipped with fail-safe features, was inoperative.

Once the product was released, other factors were conducive for vapor to accumulate in the area. The temperature was 54° F, about the same as the dewpoint, which increased the tendency of the vapor to remain close to the ground. The winds were northerly at a speed of less than 2 knots, which allowed the mostly ethane product to evaporate and cool the air below the

dewpoint, forming a fog. The terrain was gently rolling prairie; the station was atop a hill that dropped 40 feet to a low area, or swale, on the south side of the hill. The heavier-than-air vapor followed the terrain, flowing down the hillside, and filled the swale. With little or no wind to dissipate it, the vapor cloud continued to grow and remained in the area until it was ignited.

Adequacy of Safety Control Systems

This accident could have been avoided had the company done a comprehensive safety analysis of the Seminole pipeline system and Brenham station in order to identify potential points of failure and product release. Certain system components at both the dispatch center and the accident site did not allow dispatchers to readily identify an abnormal operating condition or to determine the scope of the problem. The Brenham station emergency shut-down system lacked fail-safe features.

SCADA System Format.--The SCADA pressure, flow rate, and alarm information that was transmitted to the dispatch center after 6 a.m. could have alerted a dispatcher trained in station operations that an abnormal condition had developed at Brenham station. The dispatcher's failure to identify the abnormal condition was due, in part, to his lack of training in recognizing abnormal conditions, a factor that will be covered later in this analysis under "Training."

In addition, the display format of the SCADA data did not facilitate ready identification of a problem by the dispatcher. The SCADA system format that MAPCO used before the explosion displayed only current data, and the data were in an alphanumeric format. The telemetry system updated the dispatch screens every 15 to 20 seconds, displaying pressure and flow rates for a given point in time. When the monitor displayed a reading, the dispatcher had to mentally compare the pressure shown to an established operating norm. A subsequent display of data replaced the previous display. At no time did the system monitor display a "history" of previous pressure or flow readings; such histories would have helped the dispatcher recognize trends.

Research has shown that graphic displays have several advantages over text description or tabulation.²⁹ First, graphic displays are easier to understand; thus, the user is more likely to detect trends. Second, it is easier to quickly scan and compare related sets of data; deviations are visually distinct from other data. Third, it is easier to detect critical changes, and thus easier to monitor changing data. As compared with static, printed displays, a continuous dynamic display of changing data is more likely to direct the user's attention to abnormalities.

The Safety Board concludes that had the SCADA system monitor displayed pressure and flow information in a graphic format for an extended time interval, such as shown in figure 16,

²⁹ S. Smith & J. Mosier, "Guidelines for designating user interface software" (1986). Prepared for the United States Air Force, Hanscom Air Base, Massachusetts.

a properly trained dispatcher could have more easily recognized that it was abnormal for HVLs to continue to flow into the cavern after the pump had shut down. Consequently, he would have had time to close the Bryan Lateral valve before the cavern overfilled. Even if he had not recognized the abnormality until 6:40 a.m. or later, too late to stop the release of HVLs from the cavern, he would have been able to give local agencies and his management early warning.

After the accident, MAPCO decided to graphically display both historical and current operational data on all boards at the dispatch center. Because the present SCADA transmission equipment and computer equipment and software are not compatible with a graphic display system, the company's entire SCADA system has to be replaced. It is estimated that the new SCADA system will be operational by the end of 1994.

HAZGAS Detectors.--The dispatch center received a single indication that a detector had activated. Regardless of whether an electrical malfunction or an actual HVL release activated one or more detectors, the system transmitted only one signal to the dispatch center. With the limited information provided, the dispatcher could not determine where the release had occurred, whether the release was large or small, or whether the situation was an emergency. Moreover, records show that most previous HAZGAS alarms received at the dispatch center from Brenham station had been caused by electrical problems and gas detector malfunctions. Consequently, the dispatcher could not tell from a HAZGAS alarm whether an actual emergency existed.

The Board believes that the existence and extent of a hazardous gas release would have been apparent to the dispatcher had Tulsa received either separate sequential alarms from each detector that activated or a "zone" signal when a set of detectors activated within a given area of the station. The Safety Board believes such an arrangement would allow management and employees to feel confident that they can tell when to take emergency actions, such as stopping all flow into, through, and out of stations, and when to notify local emergency agencies.

Emergency Shut-down Device (ESD).--When the Tulsa dispatch office received an emergency signal from the Brenham station, the dispatcher could only regulate pumps and valves to alter flow into and out of the station piping; he could not activate the ESD or otherwise close the cavern safety valve. The station ESD was designed to close automatically and to display to the dispatcher that it was closed. Given this arrangement and the limited information provided on operating conditions, the dispatcher's only course of action upon receiving a HAZGAS alarm from an unattended station was to notify an employee in the field or at home and to wait for him to check out the cause of the alarm. As this accident demonstrates, the consequences are a considerable loss of time and a considerable reduction in the ability of both the pipeline operator and the community to take prompt action.

The cavern wellhead valve was the only device for preventing an HVL release from the cavern. If the pressure monitoring system did not detect higher than normal pressures in the tube (an indication that HVLs had been released into the brine tube), the station safety control system

had no backup mechanism that could prevent a product release into the air.

Sensing Line Design.--Using system safety analysis procedures, the Board identified many design deficiencies in the brine pressure sensing line and potential equipment malfunctions, any one of which could disable the sensing system without the pipeline company's knowledge (see figure 22). Also, the shut-down system design did not have any alternate way of remotely or automatically closing the cavern valve if the sensing system was rendered inoperative.

Fracture in the brine pressure sensing line
Break in the electric signal wire between Barksdale switch and solenoid valve
Blocked brine pressure sensing line (from salt crystals, rust, and/or foreign debris)
Malfunction of Barksdale pressure switch or electric solenoid valve
Failure of lever arm release mechanism to rotate

Figure 22. Factors that could disable the sensing system.

Past Safety Board Actions.--The failure of pipeline operators to perform safety analyses of their systems for potential systemic deficiencies is an issue that the Safety Board has addressed repeatedly for more than 20 years.

In a 1972 special study³⁰ the Safety Board reviewed systems analysis techniques and discussed their potential for improving pipeline safety. The Safety Board concluded that by using a systematic approach to safety, operators could predict and forestall most pipeline accidents. The Board further recognized that hazard control requires a trade-off between the application of resources and the practicality of risk assumption, stating:

For pipeline managers to make sound decisions on risk assumption or reduction, they must first identify the hazards of a system, make an assessment of the risks posed in terms of probability of occurrence and potential losses, and then develop alternatives to risk acceptance and assess each in terms of available alternatives, costs of alternatives, and the extent of risk reduction.

The Safety Board concluded that each pipeline operator should use system safety analysis techniques in designing, operating, and maintaining its pipeline systems. Consequently, the Board recommended that the API and the American Society of Mechanical Engineers' Gas Piping Standards Committee (GPSC) develop and encourage the use of guidelines for pipeline operators on using system safety analysis techniques. The Board also recommended that the OPS and the Federal Railroad Administration (FRA)³¹ encourage pipeline operators to use system safety analysis techniques in general and especially in their operation and maintenance programs (Safety Recommendations P-72-19 through -24).

³⁰ Special Study, *A Systematic Approach to Pipeline Safety*, (NTSB/PSS-72/1).

³¹ The DOT agency that was then responsible for liquid pipeline safety regulation.

The DOT's Assistant Secretary for Safety and Consumer Affairs responded on August 25, 1972, for both the OPS and the FRA, stating:

We agree that "System Safety" will help to point out hazards, the likelihood of their activation, alternate methods of eliminating or controlling them, risks involved, and the feasibility of corrective measures. Under such a system, risks will no longer be assumed unknowingly, but only when a management decision has been made to assume them.

The Assistant Secretary explained that due to the magnitude of such a program, the DOT believed that the program should be carried out by the whole industry in a cooperative effort. He pledged that the DOT would make its pipeline information and accident files available, that the OPS would encourage gas operators and the AGA to cooperate in developing reports and manuals on particular segments of gas pipelines, and that the FRA would encourage the API to take similar action with liquid pipeline operators. Furthermore, individual pipeline operators would be encouraged to use the systematic approach to safety for reviewing and revising their operating and maintenance procedures.

In 1975, the AGA, in coordination with the GPSC, published its *Guide to System Safety Analysis in the Gas Industry*, which states:

In the design of any vitally important transport system it is essential to anticipate and identify all possible elements or combinations of causes that might contribute to a failure so they can be eliminated at the earliest stage or design, and so that the performance of the system is predictable. This need led to the development of formalized procedures for the analysis of system safety that forced a logical examination of all elements of a system and the identification of all possible sources of accidents.

This document is intended as a guide to the more common methods and procedures used in system safety analysis. It is addressed to a technical staff member who has little or no prior experience with system safety analysis, but who may be called upon to perform such an analysis. His task might be to identify the source or causative agents of potential accidents in some phase of gas system design and operation. Once such cases are identified, he would also suggest means for corrective action and estimate the consequences of an accident if one should occur if precautions are not taken. Based on this information, management would be in a better position to decide between alternate designs and methods of operation.

After reviewing the AGA guide, the Safety Board agreed that it met the intent of its Safety Recommendations P-72-19 and -20 and on December 30, 1975, classified the recommendations "Closed--Acceptable Action."

When the Safety Board reviewed the DOT's efforts to encourage the GPSC, the AGA, the API, and pipeline operators to use system safety analyses, the Board found that the efforts

were satisfactory. On January 23, 1975, the Board classified Safety Recommendations P-72-23 and -24 "Closed--Acceptable Action."

The API advised the Safety Board that it had modified several of its recommended practices and had reviewed the industry code for liquid pipelines (ANSI B31.4-1974) to ensure that it embodied applicable systematic and proven safety analyses. The API said the code simplified the systematic consideration of pipeline design criteria because it is used throughout the petroleum pipeline industry and because it serves both as a guide and a checklist. Consequently, the API argued, for the most part, it was unnecessary to analyze each system separately. In 1986, the Safety Board replied that it had reviewed the code and found that it did not specifically advocate the use of proven safety analysis techniques to support the planning of work not specifically addressed in the code. On April 17, 1986, the Safety Board classified Safety Recommendation P-72-21 "Closed--Unacceptable Action."

On February 17, 1988, the Safety Board concluded that the API was not going to develop guidance on using system safety analysis and advised the API that Safety Recommendation P-72-22 had been classified "Closed--No Longer Applicable."

Since its 1972 special study, the Safety Board has investigated several product-release accidents in which either a dispatcher failed to realize that the data on the monitor screen represented an abnormal operating condition or a system that failed did not have fail-safe features.

In 1974, the Safety Board issued a report that discussed HVL releases at two different MAPCO facilities in Kansas.³² The report said that hazards and high-risk areas in a pipeline operation can be identified through analysis and that once identified, they can be corrected. The Board concluded that in both accidents, the component failures and resulting hazards could have been identified through system safety analyses. The Board further concluded that the pipeline monitoring system was inadequate to notify and alert the dispatcher of the problem because a pressure sensing switch had not been installed at the correct location.

Following a 1983 MAPCO gas line rupture in West Odessa, Texas, the Safety Board determined that the dispatcher had not received enough information to allow him to distinguish a change in operations from an emergency.³³ The Board also found that frequent sensory equipment malfunctions had hampered the dispatcher in finding out why the system operating alarms had gone off. In its report, the Board said that MAPCO should determine why the system's electronic transmitters had malfunctioned, make necessary changes, and improve its communication system so that dispatchers would get the information they needed.

³² Pipeline Accident Report, *Mid America Pipeline System Anhydrous Ammonia Leak, Conway, Kansas, December 6 1973* (NTSB/PAR-74/6).

³³ Pipeline Accident Report, *Mid America Pipeline System Liquefied Petroleum Gas Pipeline Rupture, West Odessa, Texas, March 15, 1983* (NTSB/PAR-84/01).

Following a 1990 Texas Eastern Products Pipeline Company line rupture in North Blenheim, New York, the Board determined that the dispatcher had not received enough information to be able to promptly detect the rupture and the resulting release. The Safety Board also concluded that the people who did the repair work before the rupture were not given adequate instructions. Based on investigation findings, the Safety Board recommended that RSPA:

Define the operating parameters that must be monitored by pipeline operators to detect abnormal operations and establish performance standards that must be met by pipeline monitoring systems installed to detect and locate leaks.(P-91-1)

On October 18, 1991, RSPA advised the Safety Board that it was undertaking a study to determine whether leak detection systems should be required on gas and liquid SCADA systems. On December 20, 1991, the Safety Board classified Safety Recommendation P-91-1 "Open--Acceptable Action" pending further response from RSPA. In May 1992, RSPA initiated a 3-year study on leak detection subsystems for SCADA systems. The first phase, which was completed in May 1993, examined the reliability, performance, interface with SCADA systems, and expected costs of various types of leak detection systems. The second phase of the study will evaluate the potential of leak-detection systems in reducing pipeline leak risks. In this phase, RSPA will evaluate how all pipeline system components affect leak detection.

The System Safety Society and other professional organizations have greatly improved safety analysis techniques in use since the Safety Board initially recommended their use. However, the pipeline industries have not adequately used the techniques even though the DOT has advocated their use and the AGA has developed guidelines to make them easier to apply. Even the OPS has not seriously considered adopting safety analysis techniques until recently. The OPS is now developing a risk-based analysis and prioritization process that it believes will provide an analytical basis for selecting from among potential pipeline safety improvement projects those that will lead to optimal use of its pipeline safety resources.

The Safety Board is encouraged by the OPS's action in using safety analysis techniques to improve the administration of the pipeline safety regulatory program. However, the Board believes that the OPS should extend its new-found appreciation of the advantages of system safety analyses by incorporating incentives into its pipeline regulations that will encourage individual pipeline operators and pipeline standards-writing organizations to also incorporate these techniques into their pipeline safety programs. The Safety Board believes that the OPS should require pipeline operators to apply system safety analyses to new and modified system designs and to evaluate the adequacy of existing underground storage systems. The OPS could motivate standards-writing organizations to use analysis techniques in assessing new or modified standards and practices by not incorporating into Federal regulations any standards that have not been appraised using safety analyses.

Postaccident Analysis and Reconstruction.--Following the accident, MAPCO analyzed the design of the Brenham station and examined employee operating and emergency response

procedures to identify systemic problems. When the company reconstructed Brenham station, it installed redundant shut-down valves, repositioned the weep hole and brine tube, and redesigned the gas detectors.

Shut-down Valves.--MAPCO installed cavern shut-down valves in the cavern HVL and brine lines and a redundant cavern safety valve in the brine tube between the wellhead and the brine ponds. These valves have pneumatic actuators and are to be spring-driven closed if a loss of air pressure occurs; they are designed to automatically close should any of the conditions shown in figure 23 occur. The valves can be operated from the dispatch center, from a control panel in the station's control building, and from key-operated controls near the station gate.

Weep Hole and Brine Tube.--MAPCO raised the brine tube higher within the cavern to provide greater clearance between the bottom of the tube and the cavern bottom and positioned the weep hole 6 feet above the bottom of the brine tube. As a result, the cavern is less likely to overflow because the amount of product needed to fill the space from the bottom of the brine tube to the weep hole has been increased by several thousand barrels.

Gas Detectors.--The company has installed additional gas detectors. Eight detectors specially designed to operate in the environs of the brine ponds have been installed around each pond, and one has been installed at the cavern wellhead piping. Other gas detectors have been installed at various locations in the station, at the pumps, at above ground piping runs, at buildings, and on the plant perimeter. Detectors around the brine ponds and the wellhead are designed to transmit an alarm to the dispatch center when a gas-in-air concentration of 50 percent of the LEL is detected. The detectors transmit a failure indication when they are activated for other reasons, such as detector failure.

All gas detectors are connected to a programmable logic computer that identifies which gas detector has been activated. Activation of any gas detector at the ponds or at the wellhead causes the cavern valves to close, pumps to shut down, remotely operable valves

Loss of electrical signal;

Failure of the station's programmable logic computer that monitored and operated the station's automatic equipment, including the gas detection system;

Loss of air supply to the valve pneumatic actuators;

Excessive heat at the wellhead;

Activation of the manual emergency shut-down button at either the well head control panel or at the station control center;

Activation of the key-operated control located at the station gate;

Activation of any brine pond gas detector or any three station gas detectors;

Activation of any of the following signals:

High/low pressure in the cavern meter piping or the cavern HVL wellhead pipe,

High flow rate in the cavern meter piping,

High pressure/flow rate from the cavern to the brine ponds

Figure 23. Conditions that will cause automatic closure of the cavern valves.

to close, and a message to be transmitted to the dispatcher identifying the location of the detector. Activation of any three other detectors in the station will trigger the same safety shut-down features.

The reconstructed underground storage safety control system at Brenham is considerably more complex and extensive. However, the company designed the system without using safety analyses to identify and document potential failures, to assess the likelihood of their occurrence, and to assess the feasibility of modifications that could eliminate or minimize potential failures. Without such an analysis, the ability of the control system to protect public safety is unknown. According to a MAPCO spokesperson, the company is currently performing safety analyses and will correct any identified deficiencies before the storage system is returned to service.

When the Brenham control system design has been finalized, MAPCO intends to accept the design as its standard for reviewing all of its other cavern storage control systems, and to make applicable improvements. MAPCO already has identified some improvements needed at other caverns by comparing the control system designs of those caverns to the proposed Brenham design. It is in the process of buying and installing the equipment needed for the improvements.

Adequacy of Cavern Management Procedures

MAPCO considered its volume accounting procedure a safeguard against overfilling its storage cavern. However, the significant opportunity for measurement and accounting errors that the procedure offered, the errors MAPCO that identified when emptying the cavern, and the fact that the procedure did not include balancing the cavern storage against product transported into and out of the Brenham station demonstrates that MAPCO's expectation was not realistic.

Accountability Measures.--MAPCO had adequate records on previous cavern measurement performance at Brenham for the Y-Grade product, but did not effectively use them in making decisions on managing the cavern storage. Had MAPCO used the records, it would have recognized that the error potential was much greater than its goal of +/- 0.25 percent. When MAPCO established its measurement accuracy goal, it installed monitoring and measurement equipment with accuracies that it believed compatible with this goal and developed a daily measurement accountability procedure that it believed would accurately reflect the daily storage volumes. During its years of operation, when it emptied the cavern and compared the quantity of stored product with the quantity shown on company records, MAPCO knew of the large differences being experienced. Even so, the company did not take steps to achieve its measurement accuracy goal.

Records show that the company often did not achieve its goal of +/- 0.25 percent accuracy. In the 4 years before the April 7 accident, the measurement was more accurate than it had been in previous years. Nevertheless, errors were as great as 2.35 percent in 1988, 2.6 percent in 1989, -0.72 percent in 1990, and -1.04 percent in 1991.

At Brenham station, several factors impeded the company's efforts to achieve its measurement goal:

Metering.--The station had meters to measure HVLs that entered the station, that were placed in or removed from the cavern, and that were delivered to Coastline. The HVL flow into the 14-inch mainline was not metered. Consequently, the company could not compare the daily measurement of HVL flows into and out of Brenham station to determine the accuracy of Brenham's measurement system. According to a MAPCO spokesperson, the reconstructed Brenham station has a meter that measures product that enters the 14-inch mainline. MAPCO will use this information to compare daily all volumes of HVLs entering and leaving the station and the storage cavern.

Specific Gravity Measurements of Mixed HVL.--The Y-Grade product is a mix of many liquids and some gases. The percentages of the various liquids and gases in the product being received at any time range constantly, but each generally stays within a specified range. The equipment used to define the composition of the Y-Grade HVL mix was not capable of accurately measuring the specific gravity of the continually changing product mixes as they were metered at various locations in the station. Inadequate identification of the Y-Grade HVL mix specific gravity as it is metered can result in significant errors in calculating the volume of HVLs stored in the cavern. MAPCO did not advise the Safety Board of any improvements in its specific gravity measurement procedures.

Employee Error.--The Safety Board found that employees at Brenham made many errors in obtaining and using the measurement data necessary to compute the flow of HVLs into and out of the storage cavern. Station employees did identify and correct some of their errors; however, the company did not identify the extent of the errors until it conducted a postaccident audit of all deliveries to and from the cavern. The Safety Board considered how the employee errors in MAPCO's accounting procedures affected the quantity of product stored in the cavern and found their effect to be significant, but insufficient by themselves to have caused the overfill. As a result of using incorrect temperatures, pressures, and meter correction factors in calculations, company records showed 31,000 fewer barrels of product in the cavern on April 7 than the quantity indicated by the subsequent audit.

Of potential measurement and accounting errors identified, the Board concludes that MAPCO's inability to balance cavern storage against station receipts and deliveries and its inability to accurately account for the varying specific gravity of Y-Grade product were the major reasons that the cavern was unknowingly overfilled. To estimate the size of the error necessary to account for the overfill and to consider MAPCO's view that more product was stored in the cavern on March 11 than on April 7, the Safety Board recalculated storage volumes between July 12, 1991, and April 7, 1992, by applying various error percentages to the corrected flows. Figure 24 shows the result of applying a 0.8-percent rate of error to flows into the cavern, which is less than the rate of error that MAPCO previously experienced when volumes exceeded 1 million barrels. This chart shows how MAPCO could incorrectly conclude from its cavern storage records that more product was in the cavern on March 11 than on April 7.

Under this assumption, slightly more product would have been in the cavern than was found after the accident. Nonetheless, it demonstrates how company records could have indicated that more product was stored on March 11 than on April 7, when the reverse was true. The chart shows how it was possible for 51,000 more barrels of product to have been stored in the cavern than the 288,000 barrels indicated in company records for April 7. The graph also shows that since the beginning of March, MAPCO often exceeded the cavern's 300,000-barrel working storage capacity and that it experienced a combined measurement inaccuracy (employee and procedure errors) of about 1 percent of the total product volume metered into and out of the cavern.

Cavern storage management procedures can and should be used to prevent the overfilling of underground storage facilities. Had MAPCO measured all HVL flows into and out of the station and cavern and then compared those measurements daily, the company could have identified and corrected significant individual and systemic measurement errors. Timely identification of measurement errors would have allowed MAPCO to correct equipment malfunctions and provide employees with adequate procedures, supervision, and training. The Safety Board believes that when the liquid pipeline industry uses measurement of HVLs, especially mixed-HVL streams, as an operational safeguard, the measurement procedures should include checks and balances adequate to detect both independent and systemic errors. The RSPA should require that operators of underground storage facilities develop measurement procedures adequate to identify both independent and systemic errors.

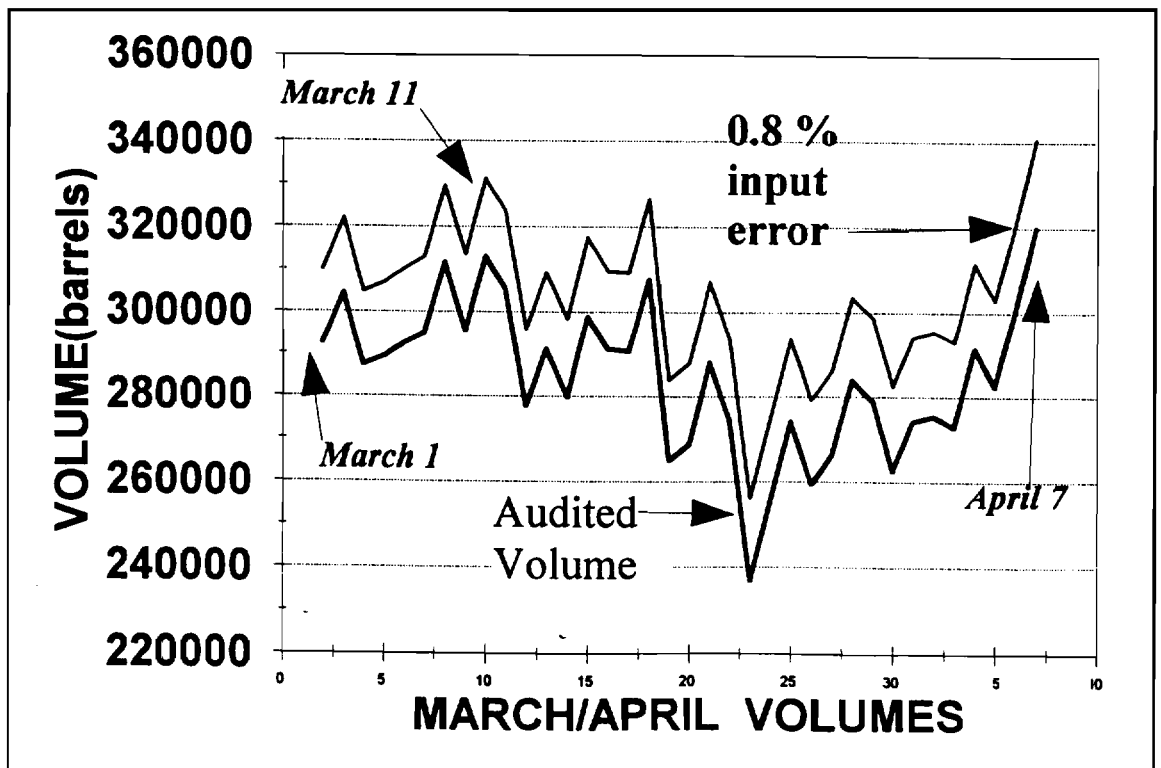


Figure 24. Above compares MAPCO's audited volumes with same volumes assuming an 0.8 percent rate of error.

For such controls to be effective, they must have a demonstrated capability to accurately measure the volume of stored HVLs. In addition, there must be an independent way to ensure that procedures are properly performed and to compare all measured flows into and out of stations that store HVLs. MAPCO now has the capability to measure all HVL flows into and out of Brenham station. The company plans to compare the station flow volumes with the cavern storage volume each day. A supervisor will also review measurement records and employee calculations daily. As stated earlier, MAPCO representatives have said that they are reviewing all storage cavern conditions and will upgrade them to be consistent with those at Brenham.

Employee and Management Performance

The Safety Board identified several factors that possibly resulted in human error and contributed to the accident and its severity. They included communication, supervisory oversight, training, dispatcher work/rest cycles, and drug impairment.

Communication.--Under the MAPCO emergency response procedures, the dispatcher is the main link in the chain of command that employees use in establishing communication. Deficiencies in communications among employees during the accident resulted in a series of other failures. For instance, the two employees who approached the station from the north about 7 a.m. did not initially communicate their location and observations to the dispatcher. When the first employee on-scene, who was unaware that any other personnel were in the area, learned that a schoolbus was headed toward the area, he left his position, where he should have been establishing a roadblock, and at risk to his own life, ran to intercept the bus. Shortly after that, a woman drove her car through the point where the blockade was inadequately established into the gas-filled area and may have ignited the products. The Safety Board concludes that the lack of communication adversely affected coordination among employees, increased the risk to initial responders, and ultimately contributed to the failure of employees to establish roadblocks that would have prevented the public from entering roads surrounding the cavern.

The Safety Board further examined the effect of inadequate communication on the dispatcher, who reported that the first technician on-scene at Brenham station did not indicate the magnitude of the gas release. Consequently, the dispatcher did not have a chance to prepare himself for the necessary procedures that followed: monitoring and operating the SCADA system, giving directions to other dispatchers, and talking on the phone to the on-site personnel and emergency-related agencies. Because the dispatcher did not have a complete understanding of the situation, he did not follow company procedure and contact the local emergency response agencies and company management. The Safety Board believes that had MAPCO provided the dispatcher with procedures for identifying the relevant product release information that he needed from on-site personnel, he would have become aware of the situation at the Brenham station and could have taken appropriate emergency response actions.

Complex tasks, such as those performed by pipeline dispatchers, involve more than sim-

ply detecting and responding to infrequent critical events. These operations require continuous attention to visual and auditory signals to detect and identify incoming information, followed by interpretations of significance, decisions concerning appropriate action, implementation of actions, and evaluation of consequences.³⁴

The ability to perform tasks effectively is influenced by operator work load, which is based on environmental demands and operator capacity. Operators are most reliable under moderate levels of work load that do not change suddenly or unpredictably. Work load can increase whenever unexpected events occur, such as faulty equipment or a breakdown in communications. Work load extremes increase the likelihood of error, especially if the operator is not adequately trained for emergencies, because he is unable to cope with the high information rates imposed by the environment. As work load increases beyond an optimal level, stress also increases, which is associated with an overall loss or decrement in ability to perform complex operational tasks. The effects of high stress levels include eroded judgment, compromised performance, inattention, loss of vigilance and alertness, and preoccupation with a single task.

The detrimental effects of excessive work load quite likely affected the dispatcher's ability to perform all tasks effectively. After talking with the on-site technician, the influx of information directed to the dispatch center required that the dispatcher handle numerous operations, including attempting to shut the Bryan Lateral valve, giving orders to other dispatchers, reopening the lateral valve, talking with on-scene personnel, and continuing to monitor the system. The Safety Board believes that the dispatcher's need to manage several tasks concurrently placed him a situation of work overload. This condition was probably exacerbated by confusion and uncertainty due to inadequate communication among the pipeline employees. As a result, the dispatcher's ability to decipher available information may have been jeopardized, thereby delaying necessary emergency response actions. For instance, while monitoring the SCADA system, he received several pressure and flow rate alarms that indicated abnormal operating conditions. Determining the significance of these alarms and taking immediate emergency response actions required him to integrate the information with other data presented earlier on the SCADA system. The Safety Board believes that the combination of a heavy work load, the inadequate display of the SCADA output, and a lack of well-rehearsed training for cavern emergencies made it difficult for the dispatcher to integrate and properly interpret the significance of the SCADA information.

The importance of communication, coordination, and task allocation during an emergency cannot be overemphasized. Failure in any of these areas can result in people being removed from the decision-making process or becoming overwhelmed by an influx of information. To avoid the possibility of task overload, emergency response procedures should focus on relieving a single employee of added pressures and responsibilities. Distribution of emergency response actions would facilitate communication and strategic planning among the employees responding to the crisis. In this accident, an effective allocation of the responsibilities among other employ-

³⁴ R. Thackray & R. Touchstone, "Effects of high visual taskload on the behaviors in complex monitoring," *Ergonomics* 32 (1989), pp. 27-38.

ees would have allowed for the efficient execution of required tasks, such as notifying the local emergency response agencies, thereby reducing the "chaotic" environment experienced by the dispatcher. The Safety Board concludes that MAPCO's emergency procedures and training did not adequately prepare its employees in effective communication and task allocation.

Supervisory Oversight.--One role of management is to supervise operations and procedures conducted by employees. In this accident, inadequate management supervision allowed measurement errors to go undetected. The Safety Board found that employees made numerous measurement errors in determining the flow of HVLs into and out of the storage cavern. These errors occurred despite the fact that supervisors did some mathematical checks of figures, made on-site inspections, and held face-to-face discussions with employees to determine whether the employees correctly understood how to calculate the quantity of product in the cavern. Although MAPCO may have considered accurate measurement a safeguard against overfilling the cavern, the fact that numerous calculation errors went undetected over an extended period suggest that management's efforts to ensure effective cavern management were not effective.

MAPCO had trained Brenham station employees in the proper procedures to follow when performing measurements. However, the company neither tested employees to determine whether they understood the procedures nor sufficiently supervised or otherwise monitored them to ensure that they were performing their work correctly.

The Safety Board determined that Brenham station employees did detect and correct some of their measurement errors; however, MAPCO did not identify the extent to which employees were making errors until the company conducted a postaccident audit of all deliveries to and from the cavern. As a quality review measure, on-site supervisors could have periodically checked a sample of the calculations themselves or tasked a second employee either to check the first employee's calculations or to take readings and perform independent measurement calculations that could be compared with the first person's readings.

Training.--No current State or Federal regulations specify the qualifications or certification that a pipeline employee must have or the manner in which he must demonstrate proficiency. As a result, each company is responsible for determining the performance standards for its own employees.

MAPCO appears committed to providing its employees with thorough training. Its training program is multifaceted, and the courses are considerable in number and cover many important issues. However, in some instances either the company did not provide written operational procedures for employees to follow or the employees failed to adhere to specified procedures for normal and emergency operations. These errors occurred during product measurement (calculation of the HVL flow into and out of the cavern), communication (failure to relay information describing the extent of the gas release and failure of employees to identify their location around the cavern), supervision (failure to effectively check employees' measurements

for accuracy), and other operations (improper inspection of the cavern valve, failure to establish adequate roadblocks, and the technician's failure to respond promptly to a HAZGAS alarm).

MAPCO did provide training for the above-mentioned operations during OJT, during in-house meetings (which included area operator/technician measurement seminars), and during safety meetings when discussing product release, blocking of highways, and evacuations. The employees' errors in these and other areas suggest that MAPCO needs to further evaluate the effectiveness of its training program.

For instance, MAPCO does not routinely administer written tests after safety instruction. Consequently, it cannot adequately evaluate its employees' acquisition of the class material. The Safety Board believes that to help ensure that class material is being mastered, employees in these courses need to demonstrate learning through formal examinations, such as those required in the Knowledge Improvement Program.

MAPCO also does not always provide opportunities for trainees to apply what they have learned. The company does not conduct emergency drills in which employees can perform safety-critical operations to demonstrate their knowledge of emergency techniques. The Safety Board believes a program of emergency procedure training is not adequate unless employees have the opportunity to practice their skills during a simulated emergency situation and receive feedback on their performances. Management must also be sensitive to the need for recurrent training because the infrequency of performing emergency response activities being trained makes it important to ensure that knowledge and skills are maintained with refresher training.

Following the accident, MAPCO provided the Safety Board with a description of its revised ongoing education and training program. Two employees in the environmental and safety department are now assigned to training full-time. Their duties are to regularly review, update, and expand the company's existing program. In addition, the training department evaluates new programs in response to regulatory, technical, or operational changes. These employees work with different committees in the company to make recommendations concerning new training or modifications to existing training.

Although MAPCO discusses lesson plans and test preparation for its in-house schools, the company does not mention the need to include testing in its safety seminars, nor does it discuss plans to include emergency drills or simulations as part of its training program.

The Safety Board previously identified shortcomings in pipeline operator training and selection in its 1987 report on accidents at Beaumont and Lancaster, Kentucky, and its 1990 report on an accident at North Blenheim, New York. In the latter, the Safety Board recommended that RSPA:

Amend 49 CFR Parts 192 and 195 to require that operators of pipelines develop and conduct selection, training, and testing programs to annually qualify

employees for correctly carrying out each assigned responsibility that is necessary for complying with 49 CFR Parts 192 or 195 as appropriate. (P-87-2)

The Safety Board advised RSPA to develop and implement an employee qualification and training program that includes the following activities:

- (a) Identification of each employee whose successful accomplishment of assigned responsibilities or tasks is a necessary part of an operator's actions for complying with Federal pipeline safety regulations.
- (b) Analyses sufficient to identify for each employee the individual jobs, tasks, and responsibilities necessary to be performed as a part of the operator's program for complying with Federal requirements. These analyses should be documented and should include routine job performance, in-plant emergency duties, and emergency responsibilities for events that occur along the pipeline right-of-way. Furthermore, these analyses should be used for establishing measurable performance standards.
- (c) Identification and implementation of the specific training methods to be employed to provide adequate knowledge to each employee for effectively carrying out applicable jobs, tasks, and responsibilities identified in the analyses.
- (d) Identification of the method(s) to be used in evaluating the effectiveness of the training, including the identification of standard(s) for acceptance.
- (e) Documentation for each employee of the training provided and training evaluations.

On March 23, 1987, RSPA issued an Advanced Notice of Proposed Rulemaking (ANPRM), Docket No. PS-94, entitled "Pipeline Operator Qualifications." The purpose of the ANPRM was to improve the competency of operator personnel, to establish licensing/ certification of operators, and to set minimum training and testing standards for employees. On April 7, 1987, the Safety Board supported the ANPRM and noted that between 1978 and 1986 it had issued 110 safety recommendations calling for the kinds of improvements suggested in the ANPRM. On June 24, 1987, because of the issuance of the ANPRM, the Safety Board classified Safety Recommendation P-87-2 "Open--Acceptable Action."

Four years later, in an October 18, 1991, letter, RSPA advised the Safety Board:

RSPA will soon issue a Notice of Proposed Rulemaking (NPRM) setting qualification standards for personnel who perform, or directly supervise the performance of operations, maintenance, and emergency response functions of gas pipelines, hazardous liquids pipelines, and carbon dioxide pipelines.

RSPA did not issue the NPRM. On April 9, 1992, it advised the Safety Board that it had been directed to "refrain from issuing any proposed or final rules for a 90-day period." RSPA advised that "this may slow the development of regulations, including those undertaken as a result of NTSB recommendations." The RSPA referenced a January 29, 1992, directive to all Federal agencies, including RSPA, stating that they should not issue proposed or final rules unless the rules were subject to statutory or judicial deadlines, responded to emergencies that posed an imminent danger to human safety, or fostered economic growth. In the same letter, all agencies were directed "to evaluate existing regulations and programs and to identify and accelerate action on initiatives that will eliminate any unnecessary regulatory burden or otherwise promote economic growth." On April 29, 1992, the January directive was extended for 120 days, and on September 15, 1992, it was extended for a year.

On September 2, 1992, RSPA informed the Safety Board that issuance of an NPRM on qualification of pipeline personnel had been delayed by the regulatory moratorium and the requirement to evaluate existing regulations to identify those that substantially impact economic growth, may no longer be necessary, or impose needless cost or red tape.

On December 24, 1992, RSPA advised the Safety Board that with the passage of the Pipeline Safety Improvement Act of 1992 (PL-102-508) and its requirement that operators test employees for qualifications, it will proceed with a rulemaking under the terms of the regulatory review directive, which exempts those rules that are statutorily mandated. RSPA further noted that if the regulatory review directive is lifted, this rulemaking will become a program priority.

In its report³⁵ on a January 17, 1992, accident at Chicago, Illinois, the Safety Board reviewed the status of Safety Recommendation P-87-2. The Board noted that RSPA had already had almost 5 years to establish qualification standards and that the Safety Board believed that achieving this objective should be a RSPA priority. The Board urged RSPA to consider the rulemaking a priority regardless of the directive, because the directive does not pertain to safety regulations and rulemaking mandated by legislation. The Safety Board also stated that it remained firmly convinced that the recommended training, qualification, and testing requirements and standards are essential. It urged RSPA to act expeditiously to amend the CFR to require that pipeline operators periodically train and test all employees assigned responsibilities that could affect public safety. On January 26, 1993, the Safety Board classified Safety Recommendation P-87-2 "Open--Unacceptable Response" and reiterated the recommendation to RSPA.

On May 11, 1993, the Safety Board again advised RSPA that it had already had more than 5 years to establish employee qualification standards and that the Safety Board believed that achieving those standards should be a RSPA priority. The Board reaffirmed its position that the recommended training, qualifications, and testing requirements and standards are essential and urged RSPA to act expeditiously on this matter. The RSPA has not yet responded.

³⁵ Pipeline Accident/Incident Summary Report, "Over-Pressure of Peoples Gas Light and Coke Company Low-Pressure Distribution System, Chicago, Illinois, January 17, 1992 (NTSB/PAR-93/01/SUM).

Dispatcher Work Schedules.--Before the morning shift on the day of the accident, the dispatcher had not worked for 72 hours and was reportedly well rested. As a result, the Safety Board found that dispatcher fatigue was not a factor in this accident. However, the Board is concerned that strenuous work schedules could influence the performance of the dispatchers. For instance, between March 1 and April 30, 1992, two dispatchers had worked as many as 8 consecutive 12-hour days. Dispatchers who have worked several consecutive days or who are on a rotating-shifts schedule are, in general, more vulnerable to performance (vigilance and decision-making) errors than are well-rested dispatchers. Neither Federal nor State regulations for Texas and Oklahoma address permissible hours of service for pipeline dispatchers and other employees. The Safety Board has recommended that the DOT examine issues concerning fatigue and hours of service (Safety Recommendations I-89-1 through -3). The status of each of these recommendations is "Open--Acceptable Action."

Drug Testing.--According to Federal pipeline regulations, each employee whose performance contributed to or cannot be completely discounted as contributing to a reportable accident is to be tested for certain illicit drugs as soon as possible but no more than 32 hours after the accident occurs. Federal regulations do not require that pipeline employees be tested for alcohol. None of the employees who were on scene at Brenham station before or after the explosion were tested for drugs. The Safety Board believes that MAPCO should not have ruled out the possibility that the performance of on-site employees could have been impaired and believes that they also should have been tested for drugs.

Nothing suggests that any of MAPCO's employees were impaired by drugs. Nevertheless, the company's failure to test its on-scene employees made it impossible to determine conclusively that drugs did not have a role. The dispatchers' samples were collected 31 hours after the accident, within the 32 hours allowed by the CFR, but so long after the accident occurred that the samples were an unreliable guide to whether drugs had been used. If a drug testing program is to be a deterrent, it must be clear to pipeline operators that a long delay in obtaining specimens is not acceptable.

The Safety Board has recommended that specimens be collected "within 4 hours following a qualifying incident or accident" (Safety Recommendation I-89-6). Additionally, the Board has recommended "testing requirements that include alcohol and drugs beyond the five drugs or classes specified in the Department of Health and Human Services (DHHS) guidelines" (Safety Recommendation I-89-7). In its April 14, 1993, letter responding to the DOT NPRM on workplace alcohol and testing, the Safety Board supported the proposed rule that specimens be collected within 2 hours of a qualifying incident. The Board stated that when collection is not accomplished within 2 hours, all blood and urine samples should be collected as soon as possible and an explanation for such delay should be submitted in writing to the administrator. The status of Safety Recommendations I-89-6 and -7 is "Open--Unacceptable Action."

In this accident, both the Texas Railroad Commission and MAPCO were uncertain about which employees should have been subjected to postaccident testing. As a result, several employ-

ees involved in the accident were not asked for samples. The Transportation Safety Institute's Pipeline Safety Division has provided guidelines for drug testing, stating that employees conducting emergency response functions are subject to postaccident testing. These guidelines also identify employees who may be subjected to testing. Thus, employees identified as emergency responders may or may not be tested, depending on their involvement in the accident. No criteria specify the response actions that determine whether employees did, in fact, contribute in the accident. The lack of criteria may result in operators interpreting the postaccident drug testing policy to their own advantage.

The Safety Board believes that guidelines need to be developed to assist operators in determining whether an employee contributed to an accident. For example, guidelines should include identifying those employees that the company has designated as first responders, that is, those employees whose specific safety-critical functions (actions and/or decisions) require that they take an active part in the accident. An operator would then know that these first responders are subject to postaccident testing. To eliminate the possibility of misinterpreting the testing policy, the Safety Board believes that RSPA should develop guidelines to help ensure that the appropriate employees undergo postaccident testing.

Adequacy of Emergency Preparedness

From the testimony of pipeline employees, area residents, and community-response personnel, the Safety Board identified several failures in emergency preparedness. The ineffective actions of MAPCO's first responders actually increased the risk to both area residents and to themselves:

- o On-scene responders failed to give the dispatcher important information about site conditions.
- o The dispatcher failed to notify local response agencies, and on-scene pipeline employees failed to effectively coordinate with them.
- o On-scene responders failed to block vehicle traffic on CR 19, which HVL fog had blanketed.

MAPCO employees also did not have ready access to personal protective equipment, such as self-contained breathing apparatus. The company's "safety trailer," which had response equipment, was in Sugar Land, Texas, approximately 87 miles from Brenham, and was not available until several hours after the explosion.

MAPCO employees also lacked portable public address equipment for alerting the public. The Safety Board recognizes that because of the large accumulation of vapor at Brenham station

and adjacent areas, pipeline personnel did not have sufficient time after they arrived on scene to evacuate all residents exposed to the released vapor. However, access to public address equipment would have afforded on-scene pipeline employees more options for dealing with area residents, such as broadcasting an alert to nearby homes or making announcements at roadblocks to oncoming motorists.

The preface to the *MAPCO Procedural Manual* used by employees states that procedures contained therein are intended to comply with requirements under 49 CFR. The Safety Board determined that both MAPCO's guidelines and Federal requirements regarding emergency response are severely lacking in specific criteria on performance, especially in the areas of timely detection, notification, and evacuation.

Despite the extremely hazardous properties of HVLs, the MAPCO manual does not list evacuation as a precautionary measure to be implemented prior to controlling a leak, but only as the final step after all initial attempts to control the release have failed. MAPCO's emergency procedures are primarily designed for small releases when the responder (technician) has time to receive a call-out, proceed to the scene, determine the reason for the alarm, and notify the dispatcher. With small releases, responders usually have sufficient time to secure the area, warn area residents, and set up blockades.

In this accident, if public safety officials had been quickly notified of the abnormal conditions, they could have prepared to evacuate people from the area of potential harm until the cause of the alarm had been verified. Valuable time was wasted when the dispatcher waited for the responding technician to verify the release. Although his action was in accordance with MAPCO procedures, the time between 6:09 and 6:45 a.m., about 35 minutes, was wasted. As noted earlier, the failure of the first responder on scene and the dispatcher to communicate vital information compounded the problems in this accident. The technician told the dispatcher that "gas was in the station yard," but did not indicate either the magnitude of the release or that it was not confined to the immediate station area. The dispatcher failed to ask for any details regarding the release. As a result, the dispatcher did not notify the local fire department, thereby negating any opportunity during the next 25 minutes for community response personnel to establish site security and control, to evacuate, or to plan for fire fighting.

The Safety Board determined that planning probably would have improved coordination between MAPCO and Washington County. Investigators determined that MAPCO had given an emergency response packet to members of the Local Emergency Planning Committee (LEPC) and that none of them suggested any revisions. Following the Brenham accident, the EMC, who was also an LEPC member, testified that he was not aware of or familiar with either the pipeline company's emergency response packet or Brenham station and had not attended any training that MAPCO had conducted at the station site.

In the Brenham accident, the EMC was in charge of the overall emergency coordination, acting not only as on-scene commander, but also as emergency medical director and public infor-

mation officer. Because an individual who was not familiar with the site or prior planning activities was directing operations at the accident scene, many key tasks were not accomplished in a timely manner, including identification of the released product and its hazards, determination of the risks involved, evacuation of the affected area adjacent to the site, and liaison with the pipeline operators.

Public safety officials and pipeline operators need to understand what they can expect from one another in an emergency. To ensure compatibility, the principals in this accident should consider incorporating the following elements in their emergency planning:

- o Immediate notification by the MAPCO dispatcher of all releases, regardless of the origin or size, to the Washington County Emergency Communications Center. An immediate notification could place predetermined emergency units on alert or standby for immediate response.
- o Predetermined meeting at the site for the incident commander to initially meet and exchange information with a predesignated representative of the pipeline. The information exchange would include released product information and a list of recommended emergency action options, resources, and personnel-protective equipment available to assist in spill control, containment, and mitigation. At a minimum, personnel-protective equipment should include sufficient self-contained breathing apparatus, appropriate hydrocarbon gas detectors, intrinsically safe radios/communication equipment, and portable road barricades.
- o Map of the area with location of exposures and locations that can be isolated, along with predetermined road control points and evacuation routes.
- o Demonstrated ability to inform, warn, advise, or alert and, if need be, evacuate the exposed public in a timely manner.
- o At a minimum, establishment of and training for all key response personnel in the incident command system. Disaster drills should be conducted to ensure the adequacy of personnel readiness; for example, an annual tabletop exercise simulating a large release at the cavern that involves multijurisdictional public response agencies and all pipeline carriers/operators in Washington County.

Within 30 days of the Brenham accident, MAPCO formed a committee for cavern redesign, including emergency response planning and coordination with Washington County. The committee proposed a redesign of the cavern and establishment of a requirement that all employees be capable of participating in emergency response to HVL operations no matter where they occur; in doing so, it sought to comply with Occupational Safety and Health Administration (OSHA) regulations, 29 CFR 1910.9, "Process Safety Management of Highly Hazardous Chemicals." In November 1992, the committee drafted new procedures, "MAPCO's Brenham Emer-

gency Action Plan," covering emergency planning, public emergency alerting, and MAPCO's emergency response actions in conjunction with the surrounding community's plan.

During August and September 1992, the EMC met on several occasions with various MAPCO representatives to discuss changes to the pipeline company's emergency response procedures. At the request of the local community, the company agreed to install a siren at Brenham station that can be activated by the sheriff's office dispatcher. Furthermore, the Brenham facility will be permanently manned 24-hours a day by MAPCO personnel when it becomes operational. As a result of the November 1992 public hearing, Washington County plans to conduct a multi-jurisdictional (Washington/Austin Counties) drill and training exercise with public response agencies to familiarize them with the recently drafted MAPCO emergency action plan and emergency warning system.

The Safety Board recognizes that the emergency action plan is intended to provide closer integration with the surrounding counties, use of a remotely activated audible alarm system, command liaison, and immediate county notification prior to station supervisor contact. Considering the concerns this accident raises, key personnel must also be familiarized with both the county's and operator's plans, including their limitations, primarily through drills and training. Moreover, the plan does not include a timetable for implementing the OSHA training requirements for MAPCO employees or an annual drill with the public response agencies, nor does it provide assurance that the public will be evacuated in a timely fashion.

In reviewing the emergency response requirements, the Safety Board notes the apparent absence of criteria for timeliness of detection, notification, and evacuation. The events and circumstances of this accident and of the North Blenheim accident show a need to develop standard procedures and guidelines for a precautionary evacuation within 1 mile of HVL facilities and to provide assurance that all HVL facilities are capable of alerting and evacuating the public in a timely fashion within 1 mile of the facility following a release. Because of the potential for widespread threats due to a release of HVL along pipelines, operators must be better prepared to serve as first responders. As this accident demonstrates, pipeline operators need to ensure timely emergency notification, coordination, and liaison with public agencies, while also taking any immediate corrective action necessary to control a release. If a cavern emergency plan is to be effective, these deficiencies must be addressed.

Because of the potential for risk at HVL and natural gas underground storage facilities, the Safety Board believes that public safety officials, such as State and local emergency planning committees, should develop emergency response plans specific to the underground storage facilities in their jurisdictions.

Regulation and Oversight of Underground Storage Systems

The safety standards issued by the OPS were not applicable to HVL or other liquid petroleum underground storage facilities, primarily because the industry standards from which OPS

derived its standards did not apply to underground storage facilities. During the 25 years the DOT has had safety jurisdiction over liquid pipeline operations, several accidents involving HVL underground storage facilities have occurred, although their consequences were not as great as at Brenham. Even so, the OPS has not acted to regulate the safety of these facilities. The Safety Board believes that the OPS should have taken at least enough notice of such accidents to have initiated reporting requirements to assist it in assessing whether additional action was warranted.

The TRC has the authority to regulate underground storage facilities. However, the TRC did not consider that its authority extended to establishing safety standards for wellhead safety control systems. Consequently, Brenham station's wellhead safety equipment was never inspected by its personnel.

MAPCO's pipeline operations were subject to the OPS pipeline safety requirements and to those of the TRC. Texas, like most other States, has a small staff dedicated to monitoring the compliance of pipeline operators with safety standards. The OPS rates the TRC's pipeline safety program as one of the nation's best, yet major inadequacies in MAPCO's operations went undetected. As discussed earlier, MAPCO's emergency preparedness coordination with communities adjacent to its pipelines, employee training and oversight, and remote monitoring of Brenham station operations were all deficient, and those deficiencies were not identified before this accident by the regulatory compliance inspections. The Board believes that the TRC and the OPS should reassess Texas' pipeline safety program to identify resources and/or system improvements that needed to minimize the potential for omissions in future compliance inspections.

This accident and the lack of regulatory public safety oversight posed by more than 1,400 liquid and more than 400 natural gas underground storage facilities demonstrate that:

- o The OPS needs to define in its regulations standards to protect the public from any threat posed by the operation of HVL underground storage facilities.
- o The API needs to complete its recommendations about solution-mined storage caverns and to develop recommendations about the other types of underground storage facilities that are used to store dangerous materials, such as HVLs and natural gas.
- o The AGA needs to cooperate with the API in completing and developing recommendations about underground storage facilities.
- o States that have HVL underground storage facilities need to develop standards to protect public safety and need to effectively oversee the facilities.

The AGA spokesperson stated that underground storage of natural gas is regulated under OPS's pipeline standards; but the OPS informed the Safety Board that it has not issued safety requirements on the underground storage of natural gas. The industry spokesperson also pointed

out that there are significant differences in the physical properties of natural gas and hazardous liquids and in the types of storage. The Safety Board recognizes these differences; nonetheless the Board believes that the underground storage of both can pose significant, albeit different, threats to public safety. The Safety Board concludes that the OPS needs to amend its natural gas pipeline safety regulations to specifically include safety standards on underground natural gas storage facilities that are adequate to protect public safety.

The OPS and the AGA spokespersons advised the Safety Board that most underground HVL and natural gas storage facilities would not be affected by any safety standards issued by the OPS because the OPS's jurisdiction applies only to those storage facilities operated in conjunction with pipelines when the stored materials are to be further transported by pipeline. Individual plants are not subject to OPS's jurisdiction, nor are those underground storage facilities at terminals where the stored materials will not be further transported or will be transported by systems other than pipelines.

In a March 14, 1988, letter to the Secretary of Transportation, the Safety Board addressed the lack of safety regulations for terminal operations where hazardous materials are interchanged among transportation modes and are stored:

Terminal facilities provide important and necessary operations in an intermodal hazardous materials transportation and distribution system, and such operations should be conducted under reasonable DOT safety regulations. The Safety Board believes that reasonable safety requirements should be established for the public and for the employees of all segments of a hazardous materials transportation system and that the DOT has been given the authority to do so by Congress The lack of regulation in any portion of a hazardous materials transfer system may compromise the safety of the entire system. Therefore, the DOT should amend its regulations to remove those sections that exclude safety requirements for hazardous materials transportation operations at intermodal facilities.

The Safety Board then recommended that the DOT:

Establish safety requirements for the movement and temporary storage of hazardous materials at intermodal transportation terminals. (I-88-1)

On September 30, 1988, the Secretary advised that the DOT was addressing the recommendation, but that it would take time to sort out the appropriate policy direction. The DOT's current safety regulations on the transportation of hazardous materials do not apply to all aspects of intermodal facility operations. While some operations at these facilities may be covered by individual regulations pertaining to specific modes of transportation, there are gaps in their coverage. The Secretary stated that RSPA has begun a review of jurisdictional authority to determine which Federal statutes may be used to regulate the operations of an intermodal facility. The analysis was to identify gaps in regulations and statutes and will be completed by

the end of 1988. The Safety Board responded on November 8, 1988, complimenting the DOT on its prompt attention to this recommendation and advising that the recommendation had been classified "Open--Acceptable Action."

The Safety Board is not aware of any further action on this recommendation and urges the DOT to expeditiously complete the assessments necessary to take final action. Additionally, the Safety Board urges the DOT to include in its analysis, if it has not already done so, a review of the actions necessary to take to regulate underground storage facilities for HVLs and natural gas when those operations are not regulated under Federal statutes on pipeline operations. Therefore, the Safety Board reiterates Safety Recommendation I-88-1.

In June 1992, the TRC surveyed all underground storage facilities in Texas to document and research the extent of safeguards and types of controls in place at underground storage facilities. The TRC received responses from all pipeline companies that actively operate storage facilities. Survey responses indicated that the design of underground storage facilities differed somewhat. For example, while most facilities used hazardous gas and fire detectors that incorporated audible alarms, the location of the alarms varied greatly. Some were at the detector, some were in a nearby control room, and some were at a remote location. One alarm sounded at the local fire department. (See appendix D for survey and results.)

Based on its findings, the TRC proposed new and amended rules. On August 17, 1992, the TRC proposed amendments to Rule 46, repeal of Rule 74, and adoption of new Rules 74 and 97 to strengthen control over underground storage in salt formations. Under the proposals, each operator/storage facility would be required to prepare a written emergency response plan for coordination with local authorities, use of warning systems, procedures for citizen and employee evacuation, emergency notification, annual emergency drills, and employee safety training. The Safety Board is pleased that the State of Texas is responding to protect its citizens; however, the Board believes that the DOT needs to develop safety standards that are applicable nationwide.

CONCLUSIONS

Findings

1. The HVLs that formed the vapor cloud and that fueled the explosion were released from the overfilled underground storage cavern because the wellhead safety system at Brenham station, which was not equipped with fail-safe features, was inoperative by one or both brine sensing line manual valves being closed.
2. At the time MAPCO designed Brenham station, the company did not use system safety analysis and therefore, at that time, did not realize the cavern shutdown system lacked several fail-safe features.

3. Federal and State regulations governing underground storage facilities for natural gas and HVLs predominantly address environmental hazards and do not require an adequate level of safety for the public and employees.
4. MAPCO was not aware of the volume of product stored in the cavern because it lacked the ability to balance the cavern storage against station receipts and deliveries, because its procedures and oversight of employee measurement activities were insufficient, and because its measurement procedures did not adequately compensate for the varying specific gravity of the Y-Grade product.
5. Because the large quantity of HVLs released at Brenham station remained undetected for an appreciable time period, responders had insufficient time to evacuate endangered residents.
6. The SCADA telemetry system monitor did not display data received from Brenham station in a format that facilitated ready interpretation by dispatchers.
7. The lack of effective communications among MAPCO employees during their response to the emergency increased the risk both to area residents and to themselves and resulted in poor emergency response coordination.
8. MAPCO was not fully aware of its employees' knowledge of operating and emergency procedures because most of company training did not include formal testing or other methods, such as exercises or drills, that required employees to demonstrate their ability to perform their duties.
9. The Safety Board could not determine whether drug impairment was a factor in this accident because not all employees involved were tested. Moreover, although Federal regulations were not violated, samples were collected 31 hours after the accident, when results were no longer reliable.
10. MAPCO's emergency response training and procedures, which are primarily designed for small releases that allow personnel time to investigate the circumstances surrounding a release, proved to be inadequate in this accident.
11. Adequate planning between MAPCO and Washington County would have improved coordination and initial response actions, including notification of public emergency response agencies and securing the immediate site area, and would have better prepared the responders and the public for the possibility of a large HVL release at Brenham station.

Probable Cause

The National Transportation Safety Board determines that the probable cause of the release of highly volatile liquids from the remotely operated and overfilled storage cavern and the resulting explosion at Brenham station was the failure of MAPCO Natural Gas Liquids, Inc., to incorporate fail-safe features in the station's wellhead safety system. The cause of the overfilling was the inadequacy of the company's procedures for managing cavern storage. Contributing to the accident was the lack of Federal and State regulations governing the design and operation of underground storage systems. Contributing to the severity of the accident was the company's inadequate emergency response procedures.

RECOMMENDATIONS

As a result of its investigation of this accident, the National Transportation Safety Board makes the following safety recommendations:

--to the Research and Special Programs Administration:

Develop safety requirements for storage of highly volatile liquids and natural gas in underground facilities, including a requirement that all pipeline operators perform safety analyses of new and existing underground geologic storage systems to identify potential failures, determine the likelihood that each failure will occur, and assess the feasibility of reducing the risk; require that operators incorporate all feasible improvements. (Class II, Priority Action) (P-93-09)

-- to MAPCO Natural Gas Liquids, Inc.:

Perform safety analyses of the safety control systems for each of your underground storage systems and, based on those analyses, modify the control systems to provide an adequate level of safety for the public and employees. (Class II, Priority Action) (P-93-10)

Develop and implement training and procedures that focus on identifying and distributing emergency-response tasks, establishing communication, and coordinating on-scene personnel for all employees who respond to abnormal and emergency situations. (Class II, Priority Action) (P-93-11)

Develop procedures for dispatchers and on-scene employees to follow when gathering product-release information during an emergency to help ensure that employees promptly disseminate essential information to company and community officials responsible for emergency response actions. (Class II, Priority Action) (P-93-12)

Incorporate testing and practice drills or other emergency-procedure exercises into your employee training program so that managers can evaluate the effectiveness of the emergency response training. (Class II, Priority Action) (P-93-13)

In cooperation with Washington County, develop disaster plans for Brenham Station that identify conditions that warrant an evacuation, that identify the extent of the area to be evacuated, and that include procedures for carrying out an evacuation. (Class II, Priority Action) (P-93-14)

--to Washington County:

In cooperation with MAPCO Natural Gas Liquids, Inc., develop disaster plans for Brenham Station that identify conditions that warrant an evacuation, that identify the extent of the area to be evacuated, and that include procedures for carrying out an evacuation. (Class II, Priority Action) (P-93-15)

Evaluate the county's emergency disaster plan to determine whether it provides timely and effective response capabilities, site security and control, and personnel evacuation; and, if it does not, make necessary amendments. (Class II, Priority Action) (P-93-16)

--to the State of Texas, Department of Public Safety:

Develop guidance for communities adjacent to highly volatile liquid underground facilities that identify conditions that warrant an evacuation, that identify the extent of the area to be evacuated, and that include procedures for carrying out an evacuation. (Class II, Priority Action) (P-93-17)

--to the American Petroleum Institute:

Expedite completion of the recommended safety practices for design, construction, operation, and maintenance of solution-mined storage caverns. (Class II, Priority Action)(P-93-18)

Develop recommended safety practices for the design, construction, and operation of highly volatile liquid and natural gas geologic underground storage facilities other than solution-mined storage facilities. (Class II, Priority Action)(P-93-19)

In cooperation with the American Gas Association, develop standards and guidelines for the design and use of graphic information display systems used by dispatchers to control pipeline systems. (Class III, Longer Term Action)(P-93-20)

-- to the American Gas Association:

Cooperate with the American Petroleum Institute in completing recommended safety practices for the design, construction, operation, and maintenance of solution-mined storage caverns and in developing recommended safety practices for other types of highly volatile liquid and natural gas underground storage facilities. (Class II, Priority Action) (P-93-21)

In cooperation with the American Petroleum Institute, develop standards and guidelines for the design and use of graphic information display systems used by dispatchers to control pipeline systems. (Class III, Longer Term Action)(P-93-22)

--to the International Association of Fire Chiefs:

Advise your members of the circumstances of the April 7, 1992, explosion at Brenham, Texas, and urge them to determine whether highly volatile liquids or natural gas underground storage facilities are located in their jurisdictions; if such facilities are present, urge that your members ensure their disaster plans identify conditions that warrant an evacuation, identify the extent of the area to be evacuated, and include procedures for carrying out an evacuation. (Class II, Priority Action) (P-93-23)

The National Transportation Safety Board also reiterated the following safety recommendation:

--To the Secretary of the Department of Transportation:

Establish safety requirements for the movement and temporary storage of hazardous materials at intermodal transportation points. (Class II, Priority Action) (I-88-1)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

CARL W. VOGT
Chairman

SUSAN M. COUGHLIN
Vice Chairman

JOHN K. LAUBER
Member

JOHN A. HAMMERSCHMIDT
Member

CHRISTOPHER A. HART, Member, concurred in the adoption of this report but did not participate in the adoption of the recommendations.

November 4, 1993

APPENDIX A

INVESTIGATION AND HEARING

Investigation

The National Transportation Safety Board was notified on April 7, 1992, of the explosion and destruction adjacent to a highly volatile liquids pipeline station near Brenham, Texas. Immediately following the accident, the Safety Board dispatched an investigation team from Washington, D.C., comprising investigation groups for pipeline operations and survival factors. Later, the Board established investigation groups for human performance and metallurgy.

Hearing

The Safety Board conducted a public hearing in conjunction with this investigation in Austin, Texas, on July 29 and 30, 1992. Parties to the hearing included Seminole Pipeline Company, the Research and Special Programs Administration of the U.S. Department of Transportation, the Texas Railroad Commission, and Washington County, Texas.

Deposition

The Safety Board took depositions in conjunction with this investigation in Washington, D.C., on September 2 and 10, 1992. Parties to these proceedings were Seminole Pipeline Company and Coastline Pipeline Company.

APPENDIX B
METALLURGIST'S REPORT

NATIONAL TRANSPORTATION SAFETY BOARD
Office of Research and Engineering
Washington, D.C. 20594

July 6, 1992

Materials Laboratory
Report No. 92-71

METALLURGIST'S FACTUAL REPORT

A. ACCIDENT

Place : Brenham, Texas
Date : April 7, 1992
Pipeline : Seminole Pipeline Company
NTSB No. : DCA 92-M-P006
Investigator: George Mocharko, ST-60

B. COMPONENTS EXAMINED

1. Six-inch diameter riser, with a flanged valve and cap, and four pipe nipples and ball valves.
2. One half of a separated fusible link (165° Globe 84 UL) and exemplar fusible links.
3. Overpressure sensing equipment connected to the tube that transports brine between above-ground brine ponds and a storage cavern, including:
 - a. 1/4 inch I.D. pressure sensing tubing,
 - b. fitting (from which the pressure sensing tubing had separated) that connects the pressure sensing tubing to the brine tube,
 - c. valve with a separated handle and the 1/4 inch tubing pulled out of one end,
 - d. Barksdale class W pressure switch (SPDT), and
 - e. shutoff valve solenoid.

C. DETAILS OF THE EXAMINATION

1. Six-inch diameter riser

The six-inch diameter riser is shown in an overall view in figure 1, after removal of sections of chain link fencing (shown at the bottom of figure 1). The majority of the riser was covered by soot deposits,

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Page 2

consistent with exposure to a fire. For the riser section, this report will discuss only the examination of the four 1/2-inch-inside-diameter nipples and ball valves that were threaded into the top of the horizontal portion of the riser section. There were two ball valves on each side of the large valve in the riser. The ball valves are indicated by arrows "1" through "4" in figure 1.

Figure 2 shows closer views of the four nipples and ball valves. The nipple from ball valve "2" had separated through the threads flush with the outside diameter of the riser. The mating faces of the fracture in this nipple are indicated by arrows "2a" in figure 1. This nipple and ball valve were painted a light blue and showed no evidence of soot accumulation or fire damage. Examination of the mating fracture surfaces on this nipple revealed that the fracture surface was on a 45 degree plane, consistent with an overstress separation. No evidence of fatigue or other type of preexisting cracking was found. Deformation of the nipple adjacent to the fracture indicated that the overstress separation was a result of bending of the nipple to the right, as the components are displayed in figures 1 and 2.

The nipples from ball valves "1", "3", and "4" were also deformed to the right at angles of 40 degrees, 30 degrees, and 10 degrees from the vertical, respectively. Nipples "1" and "3" were partially separated where they were threaded into the riser. No separations were noted on the nipple from ball valve "4".

2. Fusible links

The separated fusible link and attached chain are shown in figure 3, as received. Also shown, is one of the exemplar fusible links of the same design. The separated link came apart along the soldered joint between the two halves of the link. The other half of the link was not submitted for examination. No evidence of bending or twisting deformation was noted in the separated link.

Information supplied by the manufacturer of the link indicated that the Model "B" 165 degree link has an ambient temperature exposure limit of 100 degrees and a maximum tensile load limit of 20 pounds. Also, the links "are designed for a straight pull load application. Those applications involving a torque or twisting are to be avoided."

A scanning electron microscope (SEM) was used to examine the separated surface of the link. The features appeared nondescript and no fracture mode could be identified. The SEM examination revealed that the underlying structure of the link piece (made from a copper alloy) was completely covered with a solder alloy. X-ray energy dispersive spectroscopy of the separation surface indicated that the solder was composed primarily of lead, bismuth, nickel, and tin. Much smaller amounts of oxygen, copper, silicon, aluminum, calcium, iron, and zinc were also detected.

Two intact exemplar fusible links were inserted into a tensile testing machine and subjected to an increasing tensile load while at room temperature. Separation of both links occurred at the base of one of the end rings. No evidence of an incipient separation was noted along the soldered joints.

One end of another intact exemplar link was inserted into a vise and the other end was bent with a pair of pliers (as if to peel the soldered joint apart). This action resulted in separation along the soldered joint; however, the two pieces of the link were heavily deformed during the separation process.

3. Overpressure sensing equipment

3.1. General

Figure 4 shows an overall as-received view of most of the overpressure sensing equipment attached to the salt cavern brine tube. The equipment consisted of a fitting (removed from the brine tube), a Barksdale pressure switch, a shutoff valve solenoid (not shown in figure 4), a longer length of 1/4-inch internal-diameter pressure sensing tubing with an attached valve, and a shorter length of 1/4 inch tubing attached to the Barksdale switch. The longer length of the pressure sensing tubing had separated from the brine tube fitting at the location indicated by arrow "A" in figure 4, and material was found packed in the released end of the tubing at this location. In addition, the shorter length of the pressure sensing tubing had pulled out of one end of the valve at the location indicated by arrow "B" in figure 4, and the stem of the valve (arrow "C", figure 4) was fractured, allowing release of the valve handle.

3.2. Fitting and pressure sensing tubing separation

Figure 5 shows a closer view of the tubing and fitting indicated by arrow "A" in figure 4. The bracket in figure 5 indicates the portion of the tubing that had been inserted into the fitting. Minor kinking, consistent with an excessive sideward bending load on the tube, was noted adjacent to the inserted portion of the tubing. However, examination of the pulled-out portion of the tubing revealed only small axial scratch marks, consistent with separation of the tube from the fitting primarily as a result of direct tensile loading of the tubing.

The arrow in figure 5 indicates the material packed into the separated end of the tubing. No evidence of similar material was noted in the fitting. The material in the tubing was removed by probing it with a metal tool. The material appeared to be yellow clay-colored dirt.

3.3 Valve with separated handle and pulled-out tubing

Figure 6 shows a closer view of the valve (shown without its separated handle) and a pulled-out piece of the pressure sensing tubing. Arrow "1" in this figure indicates where the tubing had been inserted into the valve, and arrow "2" indicates where the valve handle had been attached to the valve body.

Examination of the pulled-out tubing revealed bending deformation, but no kinking, adjacent to the inserted portion of the tubing. The pulled-out portion of the tubing contained small axial scratch marks, consistent with separation of the tubing from the valve primarily as a result of direct tensile loading of the tubing.

An overall view of the valve body and separated handle is shown in figure 7. The handle appeared to be deformed in the downward direction (in the direction of the unlabeled arrow in figure 7). The handle contained an elongated slot (arrow "S", figure 7) that engaged the flat sides of the valve stem (arrow "VS", figure 7) when properly assembled. The valve stem was fractured where it entered the valve body. Heavy deposits were noted on the valve stem fracture and surrounding area. The valve is shown in figure 7 after a substantial portion of these deposits had been cleaned off, allowing an easier determination of the orientation of the handle to the stem.

Figure 8 shows the handle assembled on top of the separated valve stem with the sides of the elongated slot in the handle aligned with the flat sides of the valve stem shank. In this orientation, the handle is at an angle of approximately 75 degrees to the axis of the valve.

Figure 9 shows a closer view of the separated valve stem and adjacent portion of the valve body. The valve body contained two raised bolt heads that serve as stops for a tab on the handle. Arrows "Shut" in figures 8 and 9 indicate the fully closed stop and arrows "Open" indicate the fully open stop. The open stop contained damage (also indicated by arrow "Open", figure 9) that was consistent with the handle tab overriding the open stop as the handle is turned slightly past the fully open position. Based on the damage to the open stop and other markings on the valve body, it was clear that the handle had been last assembled onto the valve stem in the orientation shown in figure 8, as opposed to being assembled 180 degrees to the position shown in figure 8.

Detailed visual examination of the valve stem fracture surface revealed fracture features typical of an overstress separation as a result of excessive bendings loads. The fracture initiation area was located along one of the flat sides of the valve stem, at the location indicated by arrow "O" in figure 9. No evidence of fatigue cracking or other type of preexisting defect was noted on the stem fracture.

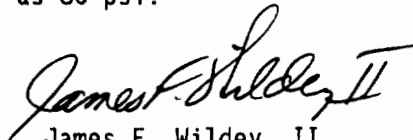
Downward loading of the handle (in the direction of the unlabeled arrow in figure 7) would produce maximum tension on the portion of the valve stem furthest from the handle. Also, loading of the handle in the direction indicated by the unlabeled arrow in figure 8 would tend to bend the valve stem because the handle is above the level of the stem. This bending would produce maximum tension in the valve stem along one of the flat sides of the valve stem (the side with arrow "0" in figure 9). Therefore, the location of the initiation area of the valve stem fracture is consistent with a combination of these two directions of loading on the handle.

Loading of the handle in the direction of the unlabeled arrow in figure 8 would also induce a torsion load on the valve stem. Evidence of this torsional loading was found on the corner of the fracture diagonally opposite from the initiation area. This corner contained a lip of metal that was smeared in the counterclockwise direction, as if the handle had been rotated toward the open position during the final stage of fracturing.

The valve was subjected to an X-ray inspection to determine the orientation of the valve ball on the inside of the valve. This inspection indicated the ball was very close to the closed position. In addition, alcohol was poured into one end of the valve, and, after waiting several minutes, none passed through the valve, consistent with a closed ball. Adding pressurized air to one end of the valve resulted in a small amount of air passing through the valve, consistent with a closed or nearly closed ball.

3.4 Barksdale pressure switch

The Barksdale pressure switch is visible in the lower left corner of figure 4. With the cover plate removed, the switch and the shut off valve solenoid were electrically connected and supplied with 110 volt power in a manner consistent with the installation before removal during the accident investigation. Increasing increments of regulated gas pressure were supplied to the pressure sensing side of the switch. The switch did not actuate, as indicated by a lack of release of the solenoid, at pressures up to 175 psi. The test was repeated several times with similar results until the switch body was lightly tapped. While being lightly tapped, it was found that the switch would actuate at various pressures as low as 80 psi.

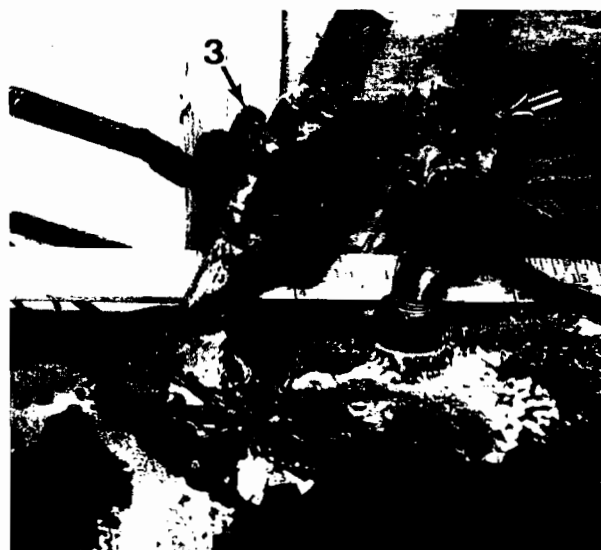


James F. Wildey, II
National Resource Specialist - Metallurgy

Supporting photographs follow



Figure 1: Overall view of the 6-inch diameter riser; arrows 1 through 4 indicate the ball valves.



Figures 2a and 2b. Close-up of ball valves and nipples. Arrow 2a shows mating fracture faces.

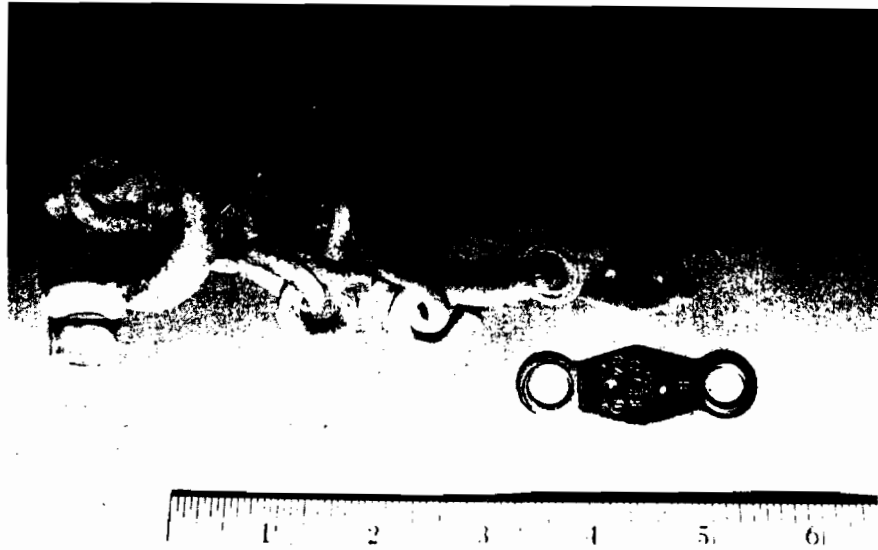


Figure 3: Overall view of the separated fusible link and attached chain (top) and an exemplar fusible link.

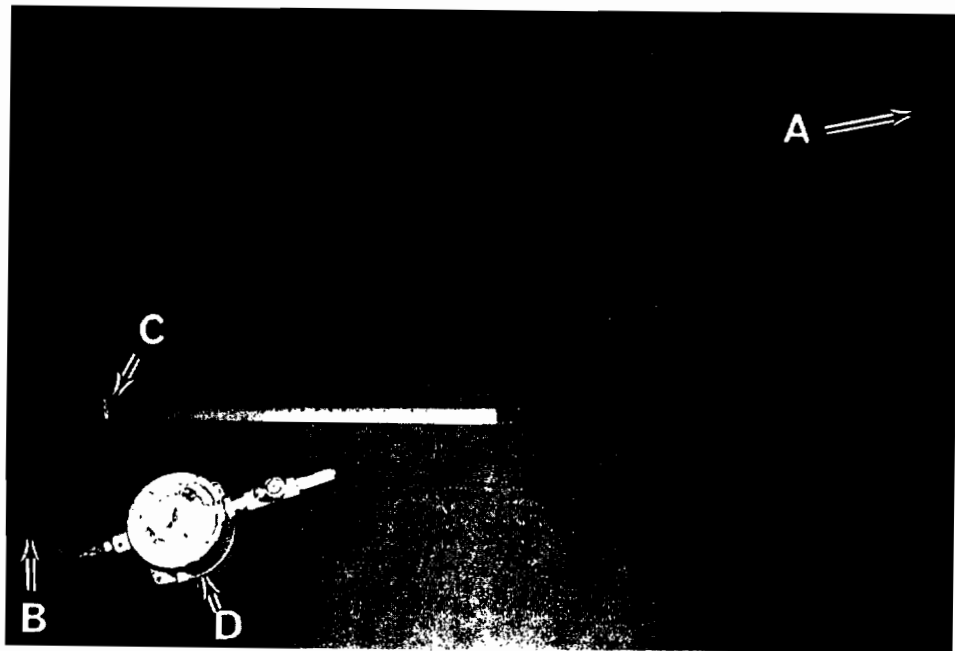


Figure 4. Overall view of pressure sensing equipment. Arrow A indicates where tubing pulled out of the brine tube fitting, arrow B indicates where tubing pulled out of the valve, and arrow C indicates the released valve handle. Arrow D indicates the Barksdale switch.



Figure 5: Closer view of tubing and fitting indicated by arrow A in figure 4. Arrow indicates material in end of tubing. The fitting is held by tweezers. X0.54

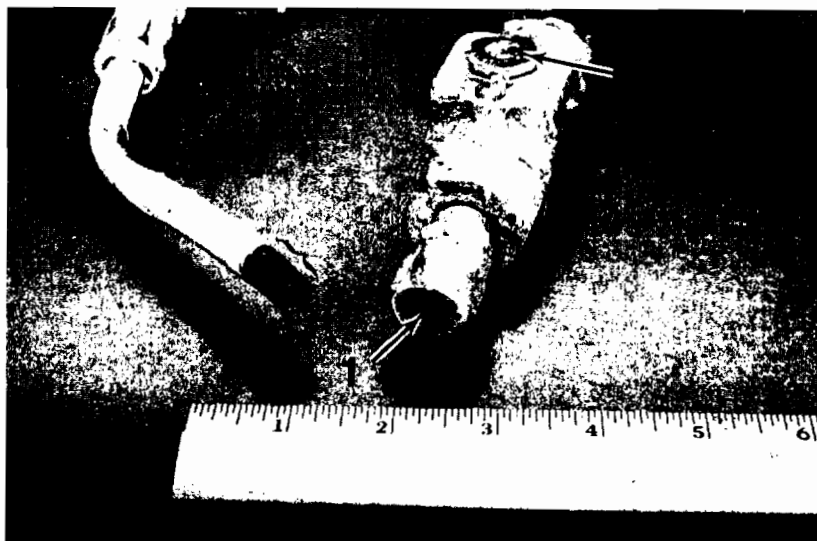


Figure 6. Closer view of valve and tubing indicated by arrow B in figure 4. Arrow 1 shows where tubing was inserted into the valve; arrow 2 shows where handle attaches to valve stem. The bracket indicates the inserted portion of the tubing.

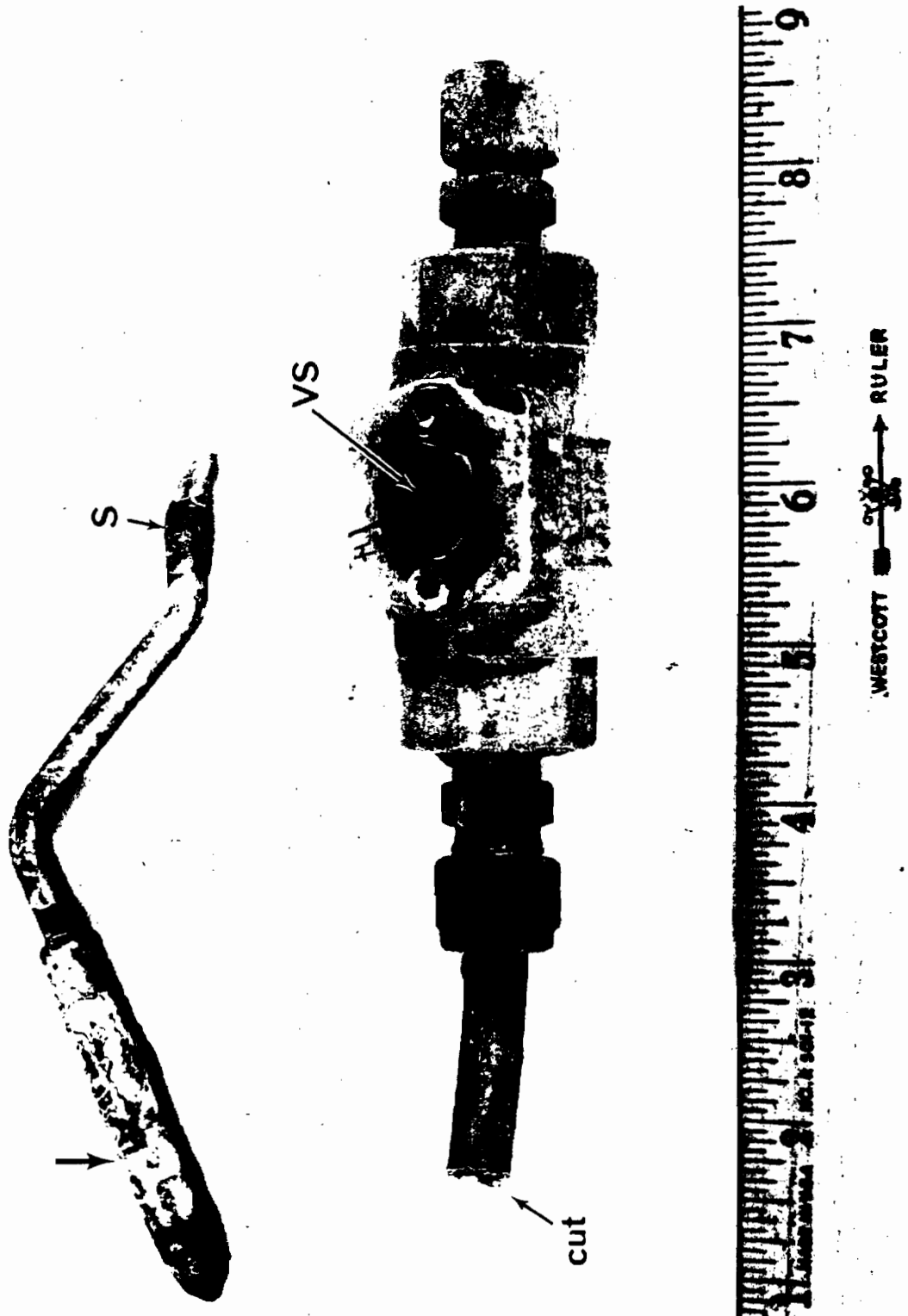


Figure 7. Overall view of valve body with separated handle. Arrow S indicates location of an elongated slot in the handle; arrow VS shows fractured valve stem.

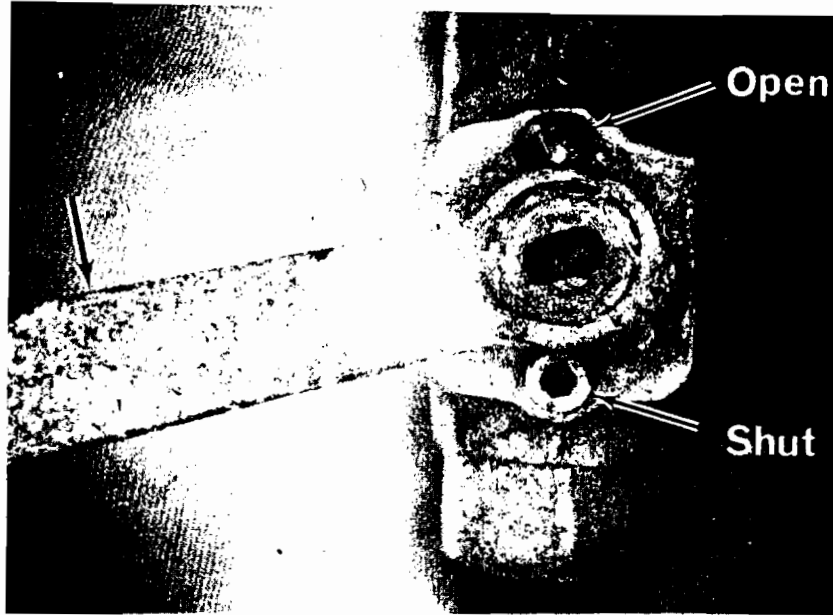


Figure 8: Valve handle assembled on top of the separated valve stem. Unlabeled arrow indicates a loading direction on handle consistent with the bending overstress separation of the valve stem.

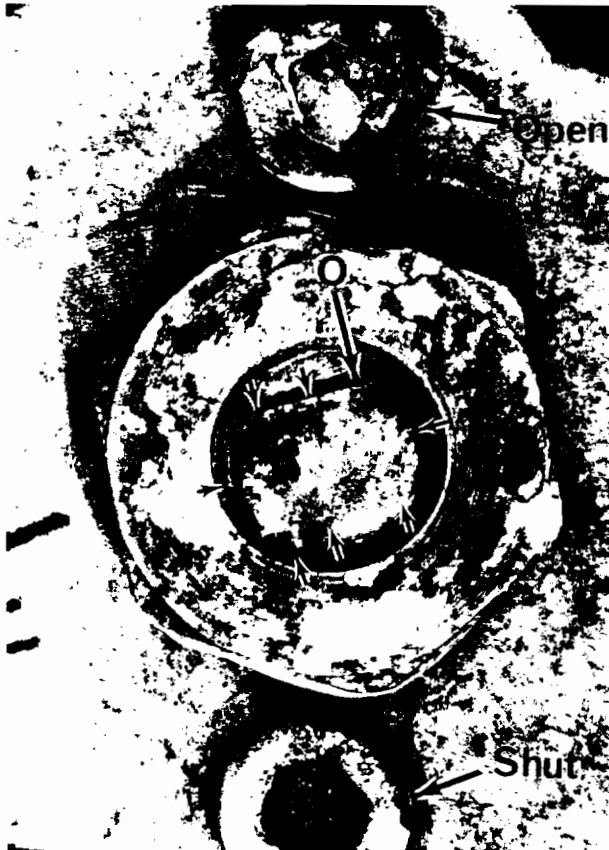


Figure 9. Closer view of fractured valve stem, after cleaning. Unlabeled arrows outline the fracture, and arrow O denotes initiation area of fracture. Arrows SHUT and OPEN indicate the fully closed and fully open stops for the handle. X4

APPENDIX C
CHRONOLOGY

April 6, 1992

AM

10:00 +/- Two manual valves at Brenham station meter run used to deliver product to Coastline are closed and locked.

MAPCO begins delivering product from plants on Bryan Lateral into cavern.

April 7, 1992

AM

- 3:30+ MAPCO computer system goes down for undetermined reasons and is restarted. Operations show as normal after computer restarted.
- 6:09:34 Dispatch center receives alarm as cavern suction pressure passes 474 psig. That pressure was shown as 546 psig.
- 6:09:39 Dispatch center receives HAZGAS alarm from Brenham station.
- 6:09:40 Dispatch center is notified that cavern pump shut down automatically.
- 6:09:50 Dispatch center receives flow rate of change alarm for Bryan Lateral. That flow rate was shown as 0 barrels per hour.
- 6:10 +/- Dispatcher notifies technician at his home of HAZGAS alarm and requests that it be checked.
- 6:30 +/- Day dispatcher replaces night dispatcher.
- 6:40:43 Dispatch center receives alarm as the mainline pump suction pressure passes 524 psig. That pressure was shown as 508 psig.
- 6:41:13 Dispatch center receives alarm as the mainline pump suction pressure passes 524 psig. That pressure was shown as 528 psig.
- 6:44:19 Dispatch center receives alarm as the mainline pump discharge pressure passes 524 psig. That pressure was shown as 520 psig.
- 6:45 +/- MAPCO technician arrives in area of Brenham station, observes fog/vapors, and parks his truck; after turning off the ignition of his truck, the engine continues to run.

- 6:45:11 Dispatch center receives alarm as the mainline pump suction and discharge pressures pass 524 psig. The suction pressure was 506 psig and the discharge pressure was 586 psig.
- 6:45:44 Dispatch center receives alarm as the cavern pump suction pressure passes 474 psig. That pressure was shown as 464 psig.
- 6:46 +/- MAPCO technician calls dispatcher, advises that vapor is in the station yard, and asks dispatcher to call his (technician's) supervisor.
- 6:46:11 Dispatch center receives alarm as the cavern pump suction pressure passes 474 psig. That pressure was shown as 528 psig.
- 6:47 +/- Technician calls his supervisor, advising that the leak is getting larger and that gas is crossing CR 19.
- 6:48:48 Dispatch center receives alarm as the cavern pump suction pressure passes 474 psig. That pressure at this time was shown as 436 psig.
- 6:48:59 Dispatch center receives alarm as the cavern pump suction pressure passes 474 psig. That pressure was shown as 500 psig.
- 6:51:02 Dispatch center receives alarm as the mainline pump discharge pressure passes 524 psig. That pressure was shown as 518 psig.
- 6:53:23 Dispatch center receives alarm as the cavern pump suction pressure passes 474 psig. That pressure was shown as 460 psig.
- 6:57:31 Dispatch center receives alarm as the cavern pump discharge pressure passes 474 psig. That pressure was shown as 466 psig.
- 6:57:54 Dispatch center receives Loss of Suction Pressure (LOSP) alarm for Bryan Lateral.
- 6:59 Resident near Brenham station calls 911 to report the odor of gas in area, that she is next to the Brenham station, that she hears something blowing out, and that there is a fog in the area.
- Brenham Fire Department reports resident's call to MAPCO dispatch center and is told that a technician has been alerted and is checking out the gas alarm.
- 7:00 +/- MAPCO pipeliner and technician trainee arrive in station area from the north to start their normal work duties. They observe vapor in area, turn off CR 19 onto station entrance road, and stop about 200 yards from station entrance gate. They

APPENDIX C

hear a noise coming from area of brine pit that sounds like a water fountain. The vapor in the area is ear-deep.

- 7:03 +/- MAPCO area operator arrives on CR 19 near Brenham station, sees vapor in area and liquid column shooting up from station, and notifies lab technician that they have "popped the top" of the cavern and that the station is engulfed in vapor cloud. Asks for instructions.
- Pipeliner walks to within 100 feet of station gate, where he observes a column of liquid rising above the brine pond.
- 7:06:04 Dispatch center receives LOSP alarm for Bryan Lateral.
- 7:06:09 Dispatcher initiates closing of Bryan Lateral valve.
- 7:06:21 Dispatch center receives notice that Bryan Lateral valve is half closed.
- 7:06:31 Dispatch center receives flow rate of change alarm for Bryan Lateral. Flow rate shown as 21 barrels per hour.
- 7:06:38 Dispatch center receives flow rate of change alarm for Bryan Lateral. Flow rate shown as 0 barrels per hour.
- 7:06:49 Dispatch center receives flow rate of change alarm on cavern line. Flow rate shown as 3 barrels per hour.
- 7:07 +/- Lab technician tells area operator to notify another employee and then calls dispatcher to advise him that a large vapor cloud is over the station and to direct him to pump product from the cavern into the mainline.
- Lab technician advises dispatcher that he sees station and that it is covered by a large mushroom-shaped vapor cloud that is more pointed at the top, that there are smaller vapor clouds to the east, and that the main cloud is growing and flowing to the east.
- 7:09:33 Dispatcher enters command to open station delivery valve to mainline.
- 7:09:48 Dispatch center receives notice that station delivery valve to mainline is half open.
- 7:10 +/- Technician arrives on CR 19 near station entrance road and meets with pipeliner and trainee. After discussion, the technician walks toward station and the pipeliner and trainee leave to block roadways.

Area operator stops woman on CR 19 from driving truck onto Glory Lane.

Area operator fails to stop car on Glory Lane from entering onto CR 19 and driving toward the station.

- 7:10:25 Dispatch center receives notice that station delivery mainline valve is open.
- 7:10:46 Dispatcher initiates opening of Bryan Lateral valve.
- 7:11:12 Dispatch center receives notice that Bryan Lateral valve is half open.
- 7:11:23 Dispatch center receives flow rate of change alarm for Bryan Lateral. Flow rate shown as 1,671 barrels per hour.
- 7:11:33 Dispatch center receives notice that Bryan Lateral valve is open.
- 7:11:40 Dispatch center receives flow rate of change alarm for cavern line. Flow rate shown as 1,650 barrels per hour.
- 7:12 +/- Car from Glory Lane turns left onto CR 19 while Area Operator is talking with driver of pickup truck on CR 19.

As Brenham Fire Department employee tries to place call to advise resident who reported the gas odor that pipeline company is checking report, he hears a loud boom, and then his phone line goes dead.

- 7:13:57 Dispatcher initiates command to close Bryan Lateral valve. Telemetry system responds with transmission error.
- 7:14:18 Dispatcher initiates command to close Bryan Lateral valve. Telemetry system responds with transmission error.
- 7:14:48 Dispatcher initiates command to close Bryan Lateral valve. Telemetry system responds with transmission error. Computer shows Brenham remote system as out of service.
- 7:14:54 Dispatcher initiates command to close Bryan Lateral valve. Telemetry system responds with transmission error.

APPENDIX D

TRC SURVEY

Phone: (512) 463-6785
Fax: (512) 463-6780

RAILROAD COMMISSION OF TEXAS

Underground Hydrocarbon Storage Facility Survey

Return to: DIRECTOR
Underground Injection Control
Oil and Gas Division
Railroad Commission of Texas
P.O. Box 12967
Austin, TX 78711-2967

INSTRUCTIONS. Please answer all questions. Check the Yes or No box or, if a question is not applicable to your facility, the NA box. For example, facilities that store only natural gas will not have brine displacement systems and facilities that store only crude oil will not have LPG loading racks and vessels. Use the remarks space at the end to provide any other pertinent information or to further explain your answers. Print or type using dark blue or black ink.

Operator Name _____ Facility Name _____
Lease Name _____ Field _____
Lease Name _____ Name _____
No. _____ County _____ RRC District No. _____

- Yes No**
A. Operations
 manned onsite 24 hours a day?
 monitored offsite 24 hours a day?
 If offsite, are well valves remotely controlled?
 Are pipeline valves remotely controlled?
 Is there a written emergency response/evacuation plan?
 TV camera surveillance?

- B. Emergency Shutdown Valves (ESVs)**
 Location: distance from wellhead: _____ feet;
 product side of well?
 brine side of well?
Actuation:
 remotely actuated?
 pressure sensor?
 heat (thermal couple)?
 fail-closed?
 Explain what causes actuation: _____

ESV operation check frequency: _____
 Describe any "breaks" in pipe between wing valves and ESVs (include valves, meter runs, blind flanges, check valves, pressure release devices, etc.): _____
 If there are any pressure measurement devices, are they in fire proof containers?

(Attaching photographs of wellheads or typical wellhead is recommended)

- Yes No NA**
C. Gas Detectors
 at wellhead?
 at transfer/storage equipment?
 at brine discharge?
 at brine pit?
 Describe locations at brine pits: _____

Gas detector testing frequency: _____

- D. Fire Detectors**
 at wellhead?
 at process equipment?
 at transfer/storage equipment?

- E. Flare/Degasifier**
 permanent flare?
 degasifier?
 at brine discharge?
 other location?
 Type of flare ignition: _____

- F. Wind Socks**
 present? Number of socks: _____
 night visible?

- G. Fire Water Systems**
 present? No. of hydrant/hose stations: _____
 Water pump engine: electrical
 internal combustion
 backup water pump?
 electrical
 internal combustion

Yes No NA

Fire Water Systems, *continued*

- wells equipped with fixed deluge or monitor nozzles?
 - nozzles/monitors remotely operated?
 - other locations with nozzles/monitors?
- Describe: _____

H. Barriers

- around wellhead?
- around meter runs?

I. Warning Systems — alarms

- connected to gas detectors?
- connected to fire detectors?
- audible at local area of detector?
- audible at control room?
- audible/visible at remote control location?
- audible/visible at public safety/fire department?

J. Storage Well Monitoring

Pressure monitoring by gauges on well

- on wellhead?
- on product side?
- on brine side?
- on safety string annulus?
- safety string exists?

Pressure monitors in control room

- monitoring product side?
- monitoring brine side?
- monitoring safety string?
- preset pressure alarms?
- pressure records kept by hard copy?
- pressure records kept by computer?

REMARKS: (attach continuation sheet if required)

Yes No NA

Storage Well Monitoring, *continued*

Volume monitoring

- of product in?
- of product out?
- of brine in?
- of brine out?

Product level monitoring

- by interface detector?
- interface detector continuous monitor?
- interface detector alarm?
- by holes in brine string?
- weep hole (window) distance above bottom of string: _____ feet;
- weep hole size: _____ inches;
- no. of holes: _____

K. Provide a plat of the facility showing pipelines and internal piping.

- Identify internal piping including product and brine piping, meter runs, pump locations, and fresh water piping.
- Identify pipelines associated with the facility and their diameters.

L. Associated LPG Facilities

- truck loading rack(s)?
- rail loading rack(s)?
- surface storage vessels? No. in use: _____
- Water capacity in gallons of each vessel in use: _____

Mark the location of loading racks and vessels on the facility plat.

Signature (company representative preparing form)

Name (print or type)

Title

Date

Phone

Company Contact

Title

Phone

UHCS49/92

Date: 09/11/92

Railroad Commission of Texas

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Underground Hydrocarbon Storage Facility Survey Summary
State Wide

	Yes	No	Non-Applicable
OPERATIONS:			
Manned 24 hours	50	13	
Monitored 24 hours	19	44	
Valves Remotely Controlled	15	47	
Pipeline Valves Remotely Controlled	31	32	
Written Emergency Response/Evac. Plan	51	12	
TV Camera Surveillance	10	53	
EMERGENCY SHUTDOWN VALVES:			
Product Side of Well	48	15	
Brine Side of Well	45	18	
Remotely Actuated	43	20	
Pressure Sensor	45	18	
Heat (Thermal Couple)	21	42	
Fail-Closed	44	19	
GAS DETECTORS:			
Wellhead	16	38	9
Transfer/Storage Equipment	33	23	7
Brine Discharge	4	39	20
Brine Pit	9	39	15
FIRE DETECTORS:			
Wellhead	14	49	
Process Equipment	18	43	
Transfer/Storage Equipment	28	35	
FLARE/DEGASIFIER:			
Permanent Flare	35	18	10
Degasifier	27	23	13
Brine Discharge	24	25	14
WIND SOCKS:			
Present	45	18	
Night Visible	37	26	
FIRE WATER SYSTEM:			
Present	40	23	
Backup Present	0	0	
Fixed Deluge or Monitor Nozzles	26	37	
Nozzles/Monitors Remotely Operated	13	50	
Other Locations with Nozzles/Monitors	24	31	
BARRIERS:			
At Wellhead	39	24	
Around Meter Runs	24	39	

Date: 09/11/92

Railroad Commission of Texas

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Underground Hydrocarbon Storage Facility Survey Summary
State Wide

	Yes	No	Non-Applicable
WARNING SYSTEMS - ALARMS:			
Connected to Gas Detectors	35	14	14
Connected to Fire Detectors	31	31	
Audible at Local Area of Detector	18	45	
Audible at Control Room	42	21	
At Remote Control Location	37	26	
At Public Safety/Fire Department	1	62	
STORAGE WELL MONITORING:			
Pressure Monitoring by Gauges on Well:			
On Wellhead	51	12	
On Production Side	54	9	
On Brine Side	45	9	14
On Safety String Annulus	22	12	29
Safety String Exists	25	38	
Pressure Monitors in Control Room:			
Monitoring Product Side	44	14	5
Monitoring Brine Side	29	22	12
Monitoring Safety String	10	24	29
Preset Pressure Alarms	40	18	5
Pressure Records Kept by Hard Copy	43	15	5
Pressure Records Kept by Computer	27	30	6
Volume Monitoring:			
Product In	58	5	
Product Out	59	4	
Brine In	24	26	13
Brine Out	23	27	13
Product Level Monitoring:			
By Interface Detector	16	46	
Interface Detector Continuous Monitor	4	59	
Interface Detector Alarm	1	62	
By Holes in Brine String	33	17	13
PLAT:			
Plat Provided	54	8	
ASSOCIATED LPG FACILITIES:			
Truck Loading Rack	23	21	19
Rail Loading Rack	11	33	19
Surface Storage Vessels	27	21	15

APPENDIX D

REVIEW OF UNDERGROUND HYDROCARBON STORAGE SURVEY INFORMATION

Summary of downhole safety methods for the 55 facilities that store LPG or crude oil.

Number of downhole safety methods, ie. safety string, interface detector, downhole brine string pressure sensor or gas sensor, or brine string weephole:

No. of safety methods used:	0	1	2	3	4
No. of facilities:	16	16	12	9	2

Number of facilities using safety strings: 24

Of the 31 facilities not using safety strings the following methods are used:

16	None (no interface detector, downhole sensor or weephole)
4	interface detector
14	brine string weephole
1	downhole gas sensor
4	combination of interface detector and weephole