LP GAS TANK EXPLOSION

Memphis, Tennessee
December 23, 1988

FIRE INVESTIGATIONS

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FIRE INVESTIGATION REPORT

Propane Tank Truck Incident
Eight People Killed
Memphis, Tennessee
December 23, 1988

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Revised 2/6/90

ABSTRACT

On Friday, December 23, 1988 at approximately 10:15 a.m., a propane tank truck overturned on a highway in a populated section of Memphis, Tennessee and released a vapor cloud. The cloud was ignited, burning several buildings adjacent to the highway and several automobiles. Eight civilians died and nine others were injured. The vapor cloud ignition also resulted in a BLEVE of the propane tank.

The 29-year-old driver reportedly had a good driving record and was familiar with the road. His truck had a propane tank with a water capacity of about 10,450 gallons and was apparently in good repair. The accident occurred in the city limits of Memphis on an exit ramp with a sharp turn.

While negotiating the turn, the driver appears to have lost control of his vehicle. The truck rolled over approximately 1 1/4 times and skidded for a distance. The tank was punctured by an unknown means, and propane was released. The expanding vapor cloud spread over several hundred feet of the highway covering all travel lanes.

Investigators believe that the vapor cloud might have been ignited when it seeped into one of the houses on the west side of the highway. The ensuing fireball ignited other houses and spread back across the highway engulfing several cars. When the burning of the vapor cloud reached the propane tank, a BLEVE occurred, and the tank broke into several pieces. The largest part traveled about 360 feet from the accident scene and struck a house, causing a fire in that structure.

In addition to the driver, two occupants of one house and an occupant of another house were killed. Four people in automobiles also died in the fire and nine people were injured. Six houses, one industrial building, and thirteen vehicles were burned. One house and five vehicles were also damaged by debris.

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I. INTRODUCTION

The National Fire Protection Association (NFPA) investigated the Memphis, Tennessee fire and explosion in order to document and analyze significant factors that resulted in the loss of life and property.

This study was funded by NFPA as part of its ongoing program to investigate technically significant incidents. NFPA's Fire Investigation Division documents and analyzes incident details so that it may report lessons learned for life safety and property loss prevention purposes.

NFPA became aware of the propane tank truck fire and explosion on the day of its occurrence, December 23, 1988. Michael S. Isner, of the Fire Investigations Division, traveled to Memphis to document the facts related to this fire. An initial two days of on-site study and subsequent analysis of the event were the basis for this report. Entry to the fire scene and data collection activities were made possible through the cooperation of the Memphis Fire Department.

This report is another of NFPA's studies of fires having particularly important educational or technical interest. The information presented is based on the best data available during the on-site data collection phase and during the report development process. It is not NFPA's intention that this report pass judgement on, or fix liability for, the loss of life or property resulting from this incident. It is NFPA's intention that the report present the findings of the NFPA data collection and analysis effort.

The cooperation and assistance of Fire Marshal H. D. Crossnine and his staff of the Memphis Fire Department Fire Prevention Bureau, and of Ms. Leslie McMillan of the National Transportation Safety Board are greatly appreciated.

The author also wishes to acknowledge the technical assistance by Mr. Theodore C. Lemoff, P.E., the NFPA Gases Field Service Engineer and Mr. Wilbur L. Walls, P.E., the NFPA Gases Field Service Engineer emeritus.

Special thanks are given to Laurie Ruszcyk, Division Secretary, for her assistance during the preparation of this report.

II. BACKGROUND

The Area and Intersection

Interstate 240 is a beltway around the center of Memphis. This is a typical limited access highway with three travel lanes in each direction. I-240 intersects with Interstate 40 at two locations. One intersection is on the east side of Memphis and the other is on the west side of Memphis approximately 2 1/2 miles from the Tennessee and Arkansas border.

I-40 is also a limited access highway with three travel lanes in each direction. This highway runs east to west through the city. The initial design of this thoroughfare directed it through a city park. When the highway was being constructed, the right-of-way through the city park was revoked, and as a result, the highway abruptly ends on each side of the park. Because I-40 is not continuous, all traffic traveling in the east or west direction have to exit I-40 and use the beltway I-240 to continue their travel through the city.

The western intersection between I-240 and I-40 (see Figure 1) falls in an residential/industrial section of Memphis. The structures in the area are predominately one- and two-story, wood-frame dwellings but there are several one-story, noncombustible commercial buildings in the area. Many of the homes in the area, like the dwelling at 1117 Waldran, did not have full basements. Instead, they have vented crawl spaces between the first floor and grade. Most of the homes were constructed before the highway and were on small lots with minimum distance between structures. Property values were relatively low compared to other residential areas in Memphis.

The grade of I-240 was about 25 feet below the grade of the surrounding properties. Large earth embankments adjust the grade differences, and several bridges above I-240, such as the Autumn Avenue bridge, allow traffic to flow between residential sections on each side of the highway. Because the highway had been constructed through an existing residential area, many homes remained along the edge of the large embankments.

The Truck

The vehicle involved in this incident was an eighteen wheel, semitractor trailer hauling propane. The trailer was owned by a Memphis based transport company and the tractor was owned by the father of the operator. The tractor was a 1986 Mack Econodyne with two rear axles. The operator was 29 years old and reportedly had a good driving record.

Manufactured at the Downingtown Iron Works Division in 1964, the trailer was designed to hold Liquified Petroleum Gas (LPG) or Ammonia, and reportedly, the trailer had not contained Ammonia for several years. The tank was constructed in compliance with I.C.C. Specification Number MC-330 and had a water capacity of 87,031 pounds

which is equivalent to approximately 10,450 gallons. The tank shell was 38 feet 3 inches long, had an outside diameter of 84.606 inches, and was constructed of 0.39 inch thick SA1517 Grade F steel with a tensile strength of 115,000 psi. The heads were constructed with the same metal, were 0.25 inches thick and had a hemispherical radius of 42 inches. Double butt welds were used during the tank assembly. The tank had a maximum working pressure of 265 psi at a maximum temperature of 150°F and had two 3-inch relief valve outlets, and two relief valves had been installed. Information regarding operating pressure of these relief valves was not available.

The tank was last tested on March 3, 1985. At that time, it passed a 400 psi pressure test, a magnetic particle test and an internal inspection of the welds. The trailer also passed the State of Arkansas vehicle inspection the day before the accident. The words "Propane" and "Flammable" and the Department of Transportation (DOT) symbol bearing the number 1075 were painted on the heads of the tank.

On the morning of the incident, the truck had been driven to a bulk terminal in Arkansas and loaded with propane. The tank reportedly contained 9,511 gallons of propane after the loading was completed.

The Fire Department

The Memphis Fire Department protects a 264 square mile community with a population of 650,000. The department's 300 operations officers and fire fighters are divided between three 24-hour shifts. Each shift has a duty chief, eight district/division chiefs, and 16 battalion chiefs. In addition to the approximately 1,330 operations personnel, there are about 120 personnel in administrative, clerical, fire prevention, dispatch, training and other positions. During the previous year, the department responded to 71,000 calls. Of those calls, 43,000 were medical, 28,000 were fire related calls and included false alarms, service and miscellaneous.

The department has 47 fire stations throughout the city and operates 49 pumpers, two squads, three aerial platforms and 23 ladder trucks. The pumpers are typically staffed with an officer, a driver/operator, and a fire fighter. The squads have a four fire fighter crew and the trucks typically have four personnel.

The fire department dispatch center is operated by at least eight dispatchers 24 hours per day. Two dispatchers manage the eight telephone lines and seven "911" lines that come into the center. A third person, called the "vocal operator" communicates with all fire stations on a separate network, dispatches fire apparatus and medical units, and keeps account of their assignments. Once the units have been dispatched, two other dispatchers conduct the radio communications with the responding fire apparatus and ambulances. The dispatcher at radio position F5 is responsible for transmissions to the fire units, and

the dispatcher at radio position F3 is responsible for the medical units. In addition, there is a watch commander, a relief person and a person assigned to administrative tasks. During incidents involving several alarms, all personnel in the dispatch center become involved in managing the information and performing the necessary tasks in the center.

Weather Conditions

December 23, 1988, started as a foggy day in Memphis. However, by approximately 10:00 a.m. the fog had cleared in the area where the accident occurred. The skies were clear, temperature was approximately 56°F, and the winds were from the southeast blowing at approximately 6 mph.

III. FIRE INCIDENT

The Accident and Explosion

On the morning of December 23, 1988, activities in the area of the western intersection of I-240 and I-40 were normal. Traffic of both cars and trucks was about average on the highway. The elderly woman who lived in the house at 411 N. Bellevue was at home and her 10-year-old granddaughter was sitting in the living room. Two residents of apartments located at 421 N. Bellevue were in their respective first and second floor apartments. Across the highway, another man lay asleep on his living room couch at 1117 Waldran Boulevard.

The loading of the propane tank at the Arkansas bulk terminal was completed at about 9:35 a.m., and the truck operator then drove his vehicle back into Tennessee to make his delivery. The truck was traveling eastbound on I-40. At about 10:15 a.m. the tank truck was on the exit ramp for I-240 northbound. Operators of the two vehicles directly behind the truck reported to the local police that they saw a large amount of smoke come from the truck. Another witness who was two or three cars behind the tank truck, indicated in his statement to local police officials that the truck swung wide on the curve and that it appeared the operator was having trouble controlling his vehicle. This last witness also indicated in his statement that the vehicle rolled over when the operator apparently attempted to pull his truck back to the left; after rolling, it began to skid.

The tractor and the trailer reportedly remained attached as it rolled over a full revolution and skidded and apparently came to rest with the trailer laying almost parallel to the Autumn Avenue bridge. The rear of the trailer was up the embankment and the tractor lay against an abutment near the exit ramp pavement. It is not known if the tractor and trailer were still attached but reports indicate that the tractor was on its wheels and that the trailer was leaning toward but not laying on its right side.

Several witnesses reported a loud hissing noise and a white cloud that began to fill the area below the Autumn Avenue bridge. In a few seconds, the cloud which was spreading to the northwest completely covered the highway and obscured the vision of motorists traveling in both directions on I-240. One man who was southbound on I-240 saw the cloud forming and attempted to drive through it. Once in the cloud, he felt like a snow bank had been dropped over his entire pickup truck and his engine stalled. He was able to coast through the cloud, restart his engine and continue to drive. Seconds after he left the cloud, it exploded into a huge fireball.

People in other cars on I-240 were not as fortunate. Seven cars in the southbound lanes and one car in the northbound lane were caught in

the fireball and most of the occupants in these vehicles were burned or killed.

The burning vapor cloud also started fires in three homes and one industrial building on the west side of I-240. When the burning vapor cloud engulfed the transport vehicle, the tractor was propelled into the southbound lane, the front head of the tank broke into several pieces, and the main part of the tank was propelled in a southeasterly direction. It appears that the tank may have struck the Autumn Avenue bridge and then traveled about 200 feet where it struck the embankment. The tank bounced back into the air, struck a tree, touched the roof of a house at 417 N. Bellevue and landed in the house at 411 N. Bellevue. While the tank was being propelled, the two trailer axles broke loose. One landed in a grassy area near the exit ramp, and the other landed in the kitchen of the house at 421 N. Bellevue.

After the explosion, many civilians in other vehicles on the highway did what they could to assist. Two tractor trailer drivers turned their trucks and blocked the southbound lanes to prevent motorists from driving into the fire area. Several individuals attempted to rescue victims from their burning cars and a civilian ambulance that happened to be on the highway immediately transported some of the injured to a hospital.

Fire Department Notification and Response

At about 10:15 a.m., a Memphis Fire Department Battalion Chief (B1) was approximately 2 blocks from 411 N. Bellevue when he heard an explosion and saw a house erupt into flames. He responded to the house at 411 N. Bellevue and people in the area told him that there was a woman in the house. Running between the burning house and the one next to it which was also beginning to burn, B1 saw a woman in the kitchen. He entered the house and brought the woman, who had already been burned, out of the house.

At 10:19 a.m., the Memphis Fire Department dispatch center received a telephone call reporting a gas explosion or something at 411 and 417 N. Bellevue. The caller also indicated that the house at 411 was on fire and that a woman next door might have been killed. Seconds later the dispatch center received a call reporting a fire near Bellevue. The telephone operator indicated that the fire department was responding to Bellevue and Autumn and the caller agreed that must be the location. While these telephone calls were being received, B1 radioed to position F5 at the dispatch center and told the radio operator that there was a two-story house well involved at Bellevue and Overton. He also requested an ambulance because he found an injured person at that location. At about the same time, the dispatch center began to receive several telephone calls jamming all the incoming telephone lines.

The vocal operator at the dispatch center initiated the first alarm for fire apparatus at 10:20 a.m. with the following transmission:

"Companies standby. This is a house that blew up. A two-story well-involved, 417 N. Bellevue at Autumn, (engines) 15-7-28, SN (snorkel) 13, T (truck) 6, FS (fire squad) 6, B (battalion chief)1, D (division chief)l, respond. This is a report of an explosion at a house. We are also getting a chemical plant, 417 N. Bellevue at Autumn, 15-7-28-FS6-T6-B1-D1 respond."

In addition to this equipment, EU 11 (emergency unit, i.e. an ambulance) was dispatched at 10:21 a.m. At 10:22 a.m., the radio operator F5 advised all responding fire crews that there were people in the house. While en route to the scene, EU 11 used an overpass bridge to cross I-240 and saw a car was burning on the highway below. He requested the assistance of another unit and the dispatch center sent another ambulance.

While responding to the house fire, Pumper 15 also crossed the highway on an overpass bridge near the accident scene. The crew saw lots of smoke all over the area, but could not determine the source. At approximately 10:22 a.m., Pumper 15 and Snorkel 13 arrived at the scene on N. Bellevue. Finding a dwelling well involved in fire and an exposed building beginning to burn, the Pumper 15 crew dropped three 2 1/2-inch hoselines; two were to be used to supply the monitor nozzle they left in the street, and the third was to be used to supply Snorkel 13. Pumper 15 then drove to and connected to the hydrant at the corner of N. Bellevue and Overton. When Snorkel 13 arrived, it parked in front of the house at 417 N. Bellevue, and fire fighters on this truck prepared to attack the fire at 411.

At 10:23 a.m. the vocal operator dispatched another battalion chief to the incident with the following transmission:

"B11 respond with the companies on this Bellevue and Autumn. We don't know exactly what we have. That's B11 respond with these other companies on this."

Within moments of this transmission, the captain from Pumper 7, which had arrived at N. Bellevue, radioed to F5 and told him that some type of (tanker) container had blown through the house. He also stated that his crew was going to lay some big lines. Pumper 7 then laid two 2 1/2-inch handlines which were eventually used by Pumper 15 and 28 crews to make an exterior attack against the fire at 411 N. Bellevue and to protect the exposed building next to it. FS6 arrived at the house fire on N. Bellevue at about 10:25 a.m., and the crew concentrated on identifying the commodity that had been in the tank that lay in the house.

Pumper 28 arrived at the scene at about 10:26 a.m. and supplied Snorkel 13 with two 2 1/2-inch supply lines. At 10:26 a.m., the radio operator

responsible for medical units (F3) sent a third ambulance to a police report of a badly burned person.

While working the scene, a member of FS6's crew noticed that there were two additional fires west of the original and informed F5 about these fires at 10:27 a.m. In response to that information, F5 indicated that the dispatch center was not aware of another fire in that area and that they would start additional companies.

Division Chief 2 (D2) told F5 that he was available and could investigate the report of fire. F5 acknowledged this action, and at 10:28 a.m, the vocal operator sent two more ambulances to the scene of a tanker explosion on the highway; the location was I-240 northbound just north of I-40. B11 arrived at the Bellevue address and began working with the crew from FS6.

At 10:30 a.m, the fire department chief signed on the air and responded to the scene. D1 who was working the scene at 411 N. Bellevue radioed F5 and stated that there was "some type of tank truck on the Interstate at the Little Rock exit (i.e., the exit from I-240 south to I-40 west) along with three automobiles". Several of the ambulances had arrived at N. Bellevue by this time, and the crews were treating the first victims they could find. These crews also found other injured people and began directing the ambulances still en route to those victims.

An assistant chief (AC) who was responding to the scene at 10:32 a.m, asked F5 if a district chief was responding to the accident on northbound I-240 at the Madison Street exit (approximately 1/2 mile south of the scene). The dispatch center acknowledged the transmission, and the AC then asked if there was any information on the type of fire on the Interstate. F5 responded that there was no additional information about that incident, and the AC stated that he would investigate. A couple of minutes later D1 requested that a full assignment be sent on the expressway, and the vocal operator dispatched three pumpers, one truck, a squad, and a battalion chief to the I-40 exit to Little Rock at 10:35 a.m. In response, the Memphis Fire Department dispatched three engines, a truck, a fire squad, a battalion chief and a division chief to the scene.

The ambulances that had been dispatched to the Interstate arrived at 10:35 a.m, one ambulance crew initially indicated that there were several cars on fire at their location and that no injuries had been found. A few moments later they radioed back and stated they would need additional ambulances on the highway because there were multiple injuries at their location.

The dispatch center watch commander began to assist in the radio transmission activities at 10:36 a.m. First, he confirmed that D1 was on the scene at Bellevue and he indicated to D1 that the dispatch center had

reports of fires on Waldran, the Interstate, and Bellevue. D1 responded that he could see three areas of smoke on the expressway west of his position (at Bellevue). The watch commander told D1 that a full assignment had been dispatched to the Interstate and that they were about to start a full assignment to a house at 410 Waldran.

D2 arrived on the Interstate (10:37 a.m.) and indicated that there were five cars and a tractor trailer on fire and asked for assistance. A pumper arrived at Waldran north of Autumn and reported that they had a two-story (actually it was two buildings - 1111/1113 and 1117 Forrest) well involved at 10:40. This pumper also reported that a business on Waldran south of Autumn was on fire and that a pumper was needed there too. At 10:42 the vocal operator responded two pumpers, a truck, a battalion chief and a district chief to Waldran and Autumn for the two-story that was well involved. Several of the responding units began to comment over the radio about delays due to traffic congestion, but by 10:52 a.m. some apparatus had arrived at both fire scenes on Waldran.

Shortly after 11:00 a.m, the fire department chief radioed the dispatch center and indicated that he felt the fires on both the east (Bellevue) and the west (Waldran) west sides of the Interstate were "pretty well under control; not knocked down yet, but under control." Fire apparatus were still committed to several fires on Waldran, the Interstate and Bellevue.

At 11:06 a.m. a pumper crew which was working a car fire near the Autumn Avenue overpass noticed that the building at 410 Waldran at Lane had fire on the roof which was reportedly penetrating into the building's interior. This pumper called F5 and told him that they could not respond because they were committed to the car fire on the Interstate. Another pumper and truck were dispatched to this report of fire.

Pumper 16 arrived at 410 Waldran at 11:13 and reported that there was smoke in the building but they could not locate the fire. Truck 3 arrived at 11:17 and reported "working" which indicated the fire was severe at the time that fire fighters arrived at this location.

Fire Squad 2 which had responded to the Interstate reported that they were in service at 11:29 a.m., this was the first unit to do so. Immediately following the status update, the dispatch center sent FS2 to a second tank truck incident on I - 240. This tank truck was carrying cooking oil and apparently flipped over when it approached the traffic jam caused by the first accident. The truck came to rest in the median strip and the driver was trapped in the tractor. He later died as a result of his injuries. In addition to FS2, a pumper, a truck, two battalion chiefs, two ambulances, and a car responded to the scene.

Other units which had been dispatched to the Interstate also began to report they were in service and returning to their respective stations.

However, some fire apparatus remained at the fire scene on Waldran until 2:30 p.m., on the Interstate until 5:29 p.m., and at 411 N. Bellevue until 6:50 p.m. when the incident was finally terminated.

Fourteen pumpers, seven trucks, nine ambulances, two squads, five battalion chiefs, four district chiefs, a light truck, an assistant chief, and the Memphis Fire Department chief responded to the accident and related structural fires. The pumpers used an estimated 162,000 gallons of water for fire suppression and 38,000 gallons of water for overhaul.[1]

During the nine hours that the propane tank incident was active, the Memphis Fire Department responded to several other fire and medical alarms. In addition to the second tank truck accident on the Interstate, which is considered a separate incident, fire apparatus responded to a fire alarm at a county building, a report of smoke in house, and seven other calls. In addition, fire department ambulances also responded to seven calls.

Casualties and Damage

Eight people died in this incident. The driver of the truck (Vehicle 1, Figure 2), the driver of a southbound car (Vehicle 8), and the driver and passenger in a second southbound car (Vehicle 9) all sustained fatal injuries and died at the scene. The driver in a southbound pickup (Vehicle 3) was burned at the scene and later died in the hospital. The male occupant of 1117 Waldran and an elderly woman living in 411 N. Bellevue were in their respectives homes, were burned, and later died in the hospital. The last fatality was a 10-year-old girl who was also in 411 N. Bellevue. She died at the scene.

In addition to these victims, nine people were injured. Five of the people were in vehicles on the Interstate and two of these people reportedly received serious injuries. Three other injured people were in the area of the Waldran structural fires and were not in vehicles. These people sustained minor smoke related injuries. The last person injured was the occupant of 421 N. Bellevue and he received minor head lacerations when the axle from the trailer crashed into and landed in the kitchen of his house close to where he was standing.

The tractor trailer truck hauling propane was destroyed during the accident and explosion. It appears that both the tractor and trailer were damaged when the vehicle rolled over and skidded. The damage to the tractor was greatly increased when the tank exploded propelling the

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[1] Water usage estimations were provided by the Memphis Fire Department and area based on the apparatus pump capacities and the estimated pump operation time. Actual water is probably lower than the values shown.

tractor into the southbound lanes of I-240 where it burned. The tank was apparently punctured when the vehicle rolled over, and this damage allowed the gas to escape. When the tank exploded, the rear head and the tank shell remained relatively intact and was propelled in a southeasterly direction. The front head broke into three pieces which were propelled to several locations. The trailer kingpin remained in the tractor fifth-wheel, and the kingpin mounting plate on the trailer was ripped apart with about one half remaining attached to the trailer.

Damage to the other vehicles shown in Figure 2 ranged from complete consumption by fire to broken glass. Seven vehicles (2, 3, 7, 8, 9, 18 and 19) were destroyed by the fire and seven other vehicles (4, 5, 6, 11, 13, 14, and 15) were damaged to some degree by fire. One car (Vehicle 12) was damaged when part of a tree which was struck by the flying propane tank fell on it. The sunroof on Vehicle 10 which was the first car behind the tank truck on the ramp was shattered by the explosion and debris. The small pickup truck that successfully drove through the propane cloud (Vehicle 16, not shown in Figure 2) received glass and paint damage most likely from sand and other debris being blown around in the cloud of escaping gas.

In addition to the damage caused by the fire, Vehicles 3, 6, and 8 had parts such as doors, roofs, or hoods that were bent outward. This damage appears to have been caused by gas being trapped in the passenger or engine compartments in these vehicles and then burning at an explosive rate when ignited. The small combustion explosions involving the trapped gas likely increased pressure in these vehicles and caused the observed damage.

The propane tank entered the northwest corner of the house at 411 N. Bellevue. Though the tank caused heavy structural damage to the rear and interior of the house, most of the exterior walls and roof were initially intact after the impact. However, before fire fighters could control the fire in this structure, the front and side walls collapsed, and the fire gutted what was left of the building's interior.

Two other buildings on N. Bellevue were also damaged. Before landing in the house at 411 N. Bellevue, the flying tank struck the roof of the house at 417 N. Bellevue and caused minor damage to the roof. In addition, the south wall of this building which faced 411 N. Bellevue was heavily damaged by fire. The rear exterior wall and the first floor kitchen of the house at 421 N. Bellevue were heavily damaged when one of the rear axles with the four tires still attached struck the house and came to rest in the kitchen.

A commercial building and three dwellings on Waldran were also damaged. A section of roof on the commercial building at 410 Waldran was burned and the fire began to extend into the building before being

extinguished. An abandoned dwelling at 1116 Waldran received minor fire damage to its exterior walls on the southeast corner of the structure, and the duplex house at 1111/1113 Waldran received heavy fire damage to its south wall and had some fire extension to the building interior.

The dwelling on Waldran with the greatest amount of fire damage was at 1117 Waldran. This building had very little exterior fire damage; however, almost every room within the building had been damaged by flames or smoke. The room with the greatest amount of damage was the living room which was located along the east wall of the building. The burn pattern extended nearly to the floor on all walls in that room. The fire and smoke stains on walls were not as low in other rooms. In fact, the stains became progressively higher above the floor as the rooms were further from the living room.

IV. ANALYSIS

The Accident

Preliminary results from the National Transportation Safety Board (NTSB) investigation of this incident indicates that the tractor and trailer had no defects which contributed to the vehicle accident. In addition, local police investigators have not determined the cause for the rollover.

However, statements from motorists who were in the area provide insight into factors which might have contributed to the accident. One witness indicated in his statement to police that the driver appeared to be travelling above the speed limit both on the Interstate and on the exit ramp. He also stated that the driver of the truck might have had trouble controlling the vehicle on the exit ramp. Other witnesses observed smoke coming from the truck once it was on the exit ramp. This smoke may have been the result of the driver applying his brakes to reduce speed.

The Release of Gas

Local fire investigators have not been able to determine exactly how the propane tank was punctured or fractured. The transport vehicle reportedly came to rest with its longitudinal axis almost parallel with Autumn Avenue and with the rear of the trailer up the embankment (facing east). Pieces from the tanks front head did not have apparent evidence of striking a blunt object like a column or beam supporting the bridge. Therefore, it appears unlikely that the front of the tank (where the initial rupture occurred) could have impacted the concrete beams supporting the Autumn Avenue bridge.

The tank did, however, have evidence of an apparent puncture by a sharp object at approximately the 11 o'clock position on the front head of the tank, as one faced the tank. It is suspected that the tank might have been punctured by a vertical support for a metal guardrail which was located near the concrete abutment for the Autumn Avenue bridge while the truck was rolling and skidding.

Once the tank was punctured or fractured, propane would have been forcefully expelled by its internal pressure which is a function of temperature. Assuming that the propane temperature was approaching the ambient air temperature and was approximately 50°F, the tank internal pressure would have been about 93 psig. At this temperature about one third of the propane would vaporize instantaneously upon release, and any escaping liquid propane would vaporize very quickly.

Several factors would have allowed the escaping propane to cover all lanes of I-240. Upon release, the liquid would begin to vaporize. Since the vapor to liquid volume ratio of propane is about 270:1, the gas would

immediately begin to fill the area around the damaged cargo vehicle. The liquid was being expelled in the direction of I-240 because the front head of the tank was punctured and the tank came to rest with its front pointed toward the highway. In addition, the 6 mph winds were blowing toward the northwest and also carried the escaping propane over the highway. The combined result was gas rapidly crossing the highway.

It appears that much of the propane was expelled from the tank before the vapor cloud ignited. One witness indicated that the cloud (from the tank) covered most of the Autumn Avenue bridge and the main concentration of the cloud covered both the north and southbound lanes of I-240 near that bridge. Another witness stated that the cloud appeared to be 100 to 150 feet high and blocked his vision of everything north of the Autumn Avenue bridge. Much of the propane in the tank would have been released to create a cloud of the size described.

Ignition and Fire Spread

Fire investigators believe, but cannot confirm, that the ignition of the vapor cloud might have occurred at the house located at 1117 Waldran. This house was apparently on the leading edge of the expanding vapor cloud. It is conceivable that the gas was diluted and within its flammable range when it reached this house. It is also conceivable that the gas could have entered the crawl space under the house through the ventilation openings for that area, and the gas could have entered the building through natural cracks and crevices. Once in the house, the gas appears to have been ignited by an unidentified source in the living room. The burn pattern on all walls in the living room extended from the ceiling nearly to the floor. No other rooms in this building or in other burned buildings on Waldran had this type of burn pattern.

The fireball created following ignition of the vapor cloud apparently ignited the two other dwellings and the commercial building on Waldran. The fireball also burned or ignited nine vehicles on the highway.

However, it does not appear that the fireball caused the fire in the home at 411 N. Bellevue. Local investigators believe that a gas line might have been broken or other fuels might have been exposed when the tank crashed into the house. They also believe that some ignition source within the house caused that fire to start.

The BLEVE

There appears to be only three mechanisms which could account for the explosive propulsion of the transport vehicle pieces. These mechanisms are:

1. Blast forces from a vapor cloud explosion.
2. Combustion within the cargo tank.
3. BLEVE of the cargo tank.

***Vapor Cloud Explosion*:** This would be the result of the rapid burning of a large propane-air mixture. The burning would occur so rapidly that it can result in an explosion which can cause structural damage to ordinary structures, can damage trees and power poles, and can move automobiles.

After the vapor cloud burned, there was none of the expected damage to structures, trees, power poles, or automobiles. In addition, none of the witnesses statements contain mention of a "woof", "womp", or other sounds when the cloud ignited; though such sounds would be expected. Accordingly, it appears that the vapor cloud did not burn fast enough to be considered an explosion or to produce enough force to move the cargo vehicle.

***Combustion within the cargo tank*:** This type of explosion could only occur if a flammable vapor-air mixture was present in the tank. Witness statements suggest and NTSB investigators believe that the vapor cloud ignition occurred in less than one minute after the truck came to rest against the Autumn Avenue bridge abutment. It appears however, that it would have taken several minutes to expell the liquid from the tank. As long as there was liquid in the tank and vapors were being expelled through the hole, air would not be able to enter the tank and create a flammable mixture. Accordingly, a combustion explosion also appears to be an unlikely explanation of the events following the ignition of the vapor cloud.

***BLEVE of the cargo tank*[2]:** This appears to be the only reasonable description of damage to the cargo tank. This BLEVE most likely happened when the burning "vapor cloud" flame front progressed back from 1117 Waldran to the front head of the propane tank - about a minute after the vehicle came to rest. At this time, all the liquid above the hole probably had been expelled and vapor probably was still discharging. Flames feeding on the escaping gas would have been confined to the

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[2] BLEVE is an acronym for Boiling Liquid Expanding Vapor Explosion. This phenomenon "is defined as a major container failure" into two or more pieces, at a moment in time when the contained liquid is at a temperature well above its boiling point at normal atmospheric pressure. The definition does not qualify the cause of the container failure or the chemical properties of the liquid. It is applicable to both flammable and nonflammable liquids. *,**

* Wilbur L. Walls, "The BLEVE - Part 1", *Fire Command.* - May 1979, Vol. 46, No. 5, pp. 22 - 24.

** Wilbur L. Walls, "The BLEVE - Part 2", *Fire Command.* - June 1979, Vol. 46, No. 6, pp. 35 - 37.

area of the front head, to the top front of the shell by the rear of the tractor cab and to the underside of Autumn Avenue bridge.

The classic loss of steel strength by fire heating in the "fire-caused" BLEVE would not occur in about one minute. However, the head could well have been severely weakened as a result of the puncture and impact forces. In fact, the tank could have failed in the absence of flame as occurred in Waverly, Tennessee on February 24, 1978.[3]

The fact that the tank travelled only 360 feet is not surprising even though there was some liquid propane in the tank. Unlike previous incidents where stationary tanks have travelled 1,600[4] and 2,600[5] feet, the tank in this incident still had a few thousand pounds of running gear attached, it had to overcome the restraint of the attached 5th wheel mounting, and it lost considerable energy when it hit the bridge and the embankment.

In short, the damage to the tank appears to be the result of a BLEVE - maybe not a classic one, but still a BLEVE. The tank came apart in two or more pieces at a moment in time when it still contained liquid at a temperature well above normal boiling point.

Fire Department Response

From the start of this incident, the fire fighters in the dispatch center realized that this was not a typical incident. B1 who was in the area of the explosion reported information about the incident even before the vocal operator was able to complete the initial dispatch. In addition, within moments of the first call, all the telephone lines were jammed with calls. These were indicators that something big had just happened.

As reports of fires at different locations began to surface, the dispatch center handled each report as a separate incident and dispatched fire department resources accordingly. About 1/2 hour after the initial call, a command post had been established, and fire crews were working three fire scenes on N. Bellevue, the Interstate, and Waldran. By this time, dispatchers in the communications center and the command officers on the scene knew that the fires were related to some type of tank truck explosion.

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3 "Derailments underline the need for hazardous materials training", *Fire Command*, May 1978, pp. 26 - 31.

4 *Fire Journal*, "Bi-monthly Fire Report", Vol. 69, No. 6, pg. 46.

5 Isner, Michael S., *Investigation Report, BLEVE - LP -Gas Storage Tank*, Woodruff, Utah, October 16, 1986.

The fire crews that were initially dispatched to the scene had very short response times. The first battalion chief just happened to be in the area so he arrived seconds after the explosion. Other apparatus were on the scene within two minutes because their fire stations were only a few blocks away from the scene.

As the magnitude and severity of this incident began to unfold, many more fire companies were requested and response times began to increase. Logically, the response times were affected as fire crews and apparatus came from fire stations further from the scene. But the most significant factor affecting response times was the traffic and congestion caused by the interruption of vehicle flow on the highway. Apparently, the secondary roads as well as the highway were choked with vehicles as time went on. Some of the last fire companies to respond to the scene took approximately 20 minutes to arrive as a result of the congestion.

V. DISCUSSION

The tragic incident in Memphis, Tennessee is not the first time that an propane tank truck has rolled over, exploded, and resulted in multiple civilian fatalities. On April 29, 1975, a semitrailer truck carrying 8,748 gallons of propane rolled over in Eagle Pass, Texas and exploded. This accident killed 17 people and injured 34 others. In addition, several buildings, four mobile homes, and 51 vehicles were damaged or destroyed. An important similarity between this incident and that which occurred in Memphis, Tennessee is both accidents involved tank trucks with no apparent preimpact defects which could have contributed to the accident.

Both the Memphis, Tennessee and the Eagle Pass, Texas incidents show that there are risks involved in the transportation of propane in large pressurized tanks. Though the cause of the vehicle rollover and the object that ruptured the tanks in each incident were different, the results were the same. The propane was released, and large vapor clouds were ignited. In addition, the fatalities, injuries, and property damage occurred before the fire departments were notified. Had the vapor cloud not reached an ignition source before the fire fighters arrived, the fire fighters in both incidents could have been met by a situation that was threatening to their safety as well as those civilians who might be in the area.

These incidents and others[6,7] also show that flying tank parts as a result of a BLEVE is a hazard that can be associated with the transportation of propane and other commodities. In this incident, only civilians were affected by the flying tank parts. But had the BLEVE occurred after the fire fighters arrived, they too would have been exposed to this hazard.

Accidents such as these rarely occur, but when they do, the results can be disastrous. Propane transport vehicles may be found in almost every community across the nation at some time. Therefore, fire fighters should be prepared to handle the complex incidents with multiple casualties that could arise when a large propane transport vehicle is damaged. The fire fighters should also consider their actions should they arrive before a vapor cloud ignites, and they should consider the potential for a BLEVE if it has not already occurred.

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6 "LP-Gas Distribution Plant Fire", *Fire Journal*, January 1974, Vol. 68, No. 1, p. 52.

7 "Lessons from an LP-Gas Utility Plan Explosion and Fire", *Fire Command,* April 1972, Vol. 39, No. 4, pp. 18 - 25.

VI. APPENDICES

TIME LINE

TIME	EVENT
9:35 a.m.	Operator completes filling the propane tank in an Arkansas Bulk Terminal and heads to Tennessee to make deliveries.
10:00 a.m.±	Propane truck on I-40 headed east. Motorist who is travelling about 65 mph in same direction as truck is passed by the tank truck.
10:10 a.m.±	Tank truck enters the exit ramp from I-40E to I-240N.
	Truck swings wide on turn and rolls about 1 1/4 times; front head of tank is damaged and propane begins to leak.
	Propane travelling in a northwest direction covers all lanes of the highway.
	The propane vapor cloud ignites; this most likely occurred after the propane entered the living room of the house at 1117 Waldran.
	Battalion Chief 1 (B1) sees the fireball and responds to 411 N. Bellevue.
10:19 a.m.	Memphis Fire Department receives first call reporting the fire at 411 N. Bellevue. B1 radios dispatch and also reports the fire at 411 N. Bellevue.
	Within seconds, the telephone switchboard is overwhelmed with calls reporting the fire.
10:20 a.m.	Engines 15, 7, 28, SN (Snorkel) 13, T (Truck) 6, FS (Fire Squad) 6, B (Battalion Chief) 1 and D (Division Chief) 1 were dispatched to an explosion at 417 N. Bellevue.
10:21 a.m.	EU (ambulance) 11 was dispatched to the scene.

TIME	EVENT
10:22 a.m.	Radio operator (F5) advises the responding units that there are people in the house.
	While en route EU11 sees a car fire on the highway near the Autumn Avenue bridge and tells dispatch.
	Pumper 15 and Snorkel 13 arrive at the N. Bellevue fire and prepare for their attack.
10:23 a.m.	Dispatch center dispatches a second battalion chief, B11.
	Pumper 7 arrives on scene and reports that some sort of container had blown through the house.
10:25 a.m.	Three pumpers, a truck, a fire squad, a battalion chief and a division chief are dispatched to the scene of a burning tractor trailer truck on the southbound lanes of I-240.
10:26 a.m.	Pumper 26 arrives at N. Bellevue.
	An ambulance is dispatched to a police report of a badly burned person on Fourth at Waldran.
10:27 a.m.	The crew of FS6 note that there are two fires west of the original fire at N. Bellevue and this crew tells the dispatch center.
	The dispatch center indicates that they were not aware of any other fires and that they would start additional companies.
	Division Chief 2 (D2) tells dispatch that he can investigate the report of additional fires and dispatch acknowledged the transmission.

TIME	EVENT
10:28 a.m.	Two more ambulances are sent to the scene of the tanker fire on the Interstate.
10:30 a.m.	The department chief signs on the air and is responding to the scene.
	D1 reports that there was some type of tank truck on the Interstate near the Little Rock exit and three automobiles are involved.
10:32 a.m.	A responding Assistant Chief asks dispatch if a district chief is responding to the accident northbound on I-240 at the Madison Street exit. The dispatch center had no additional information about that incident.
10:35 a.m.	D1 requests a full assignment be sent on to the I-40 exit to Little Rock.
	Two fire department ambulances arrive at the vehicle fires on the highway near the Autumn Avenue overpass.
10:36 a.m.	Dispatch center watch commander becomes involved in the dispatching activities.
	The watch commander verifies the location of one district chief and tells him that the dispatch center is aware of fires on the Interstate, N. Bellevue, and Waldran.
	A full assignment is dispatched to a house fire at 412 Waldran.
10:37 a.m.	D2 arrives on the Interstate, confirms that there is a truck and several cars involved and asks for more assistance. Dispatch indicates that equipment are already responding to that scene.

TIME	EVENT
10:40 a.m.	A pumper arriving at a house on Waldran indicated that a commercial building on Waldran was also on fire and that a pumper would be needed there too.
10:42 a.m.	The dispatch center responded two pumpers, a truck a battalion chief, and a district chief to Waldran.
10:52 a.m.	Fire apparatus begin to arrive at both fire scenes on Waldran.
11:00 a.m.	Department chief indicates that the fires on Bellevue and on Waldran were under control.
11:06 a.m.	Fire is observed on the roof of the commercial building at 410 Waldran and is reported to the dispatch center.
11:16 a.m.	The first pumper arrives at 410 Waldran and begins the attack against the fire.
	All apparatus are clear of the scenes at:
2:30 p.m.	Waldran
5:29 p.m.	I-240
6:50 p.m.	N. Bellevue

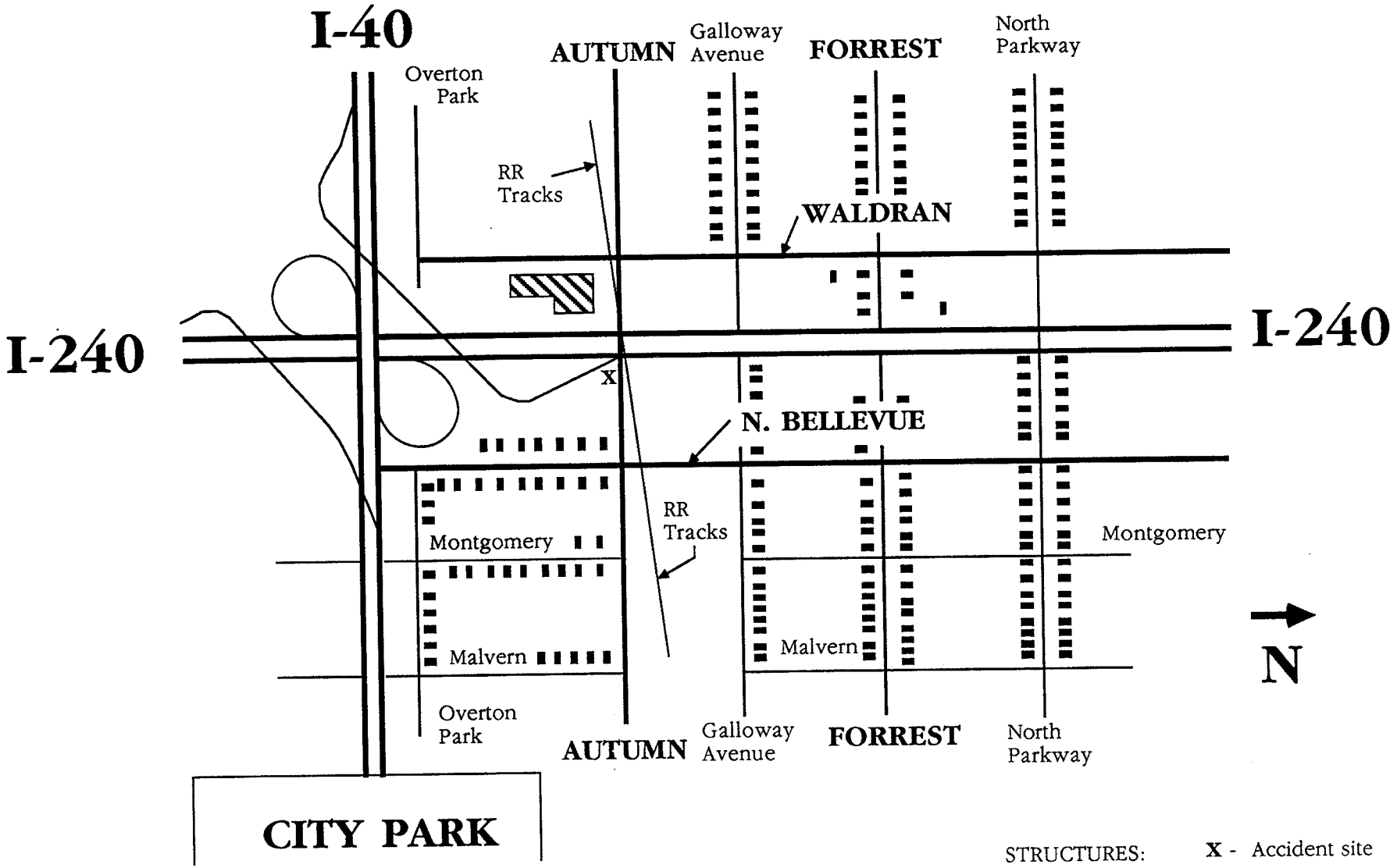

Figure 1: Western Intersection Between I-240 and I-40, and Surrounding Area

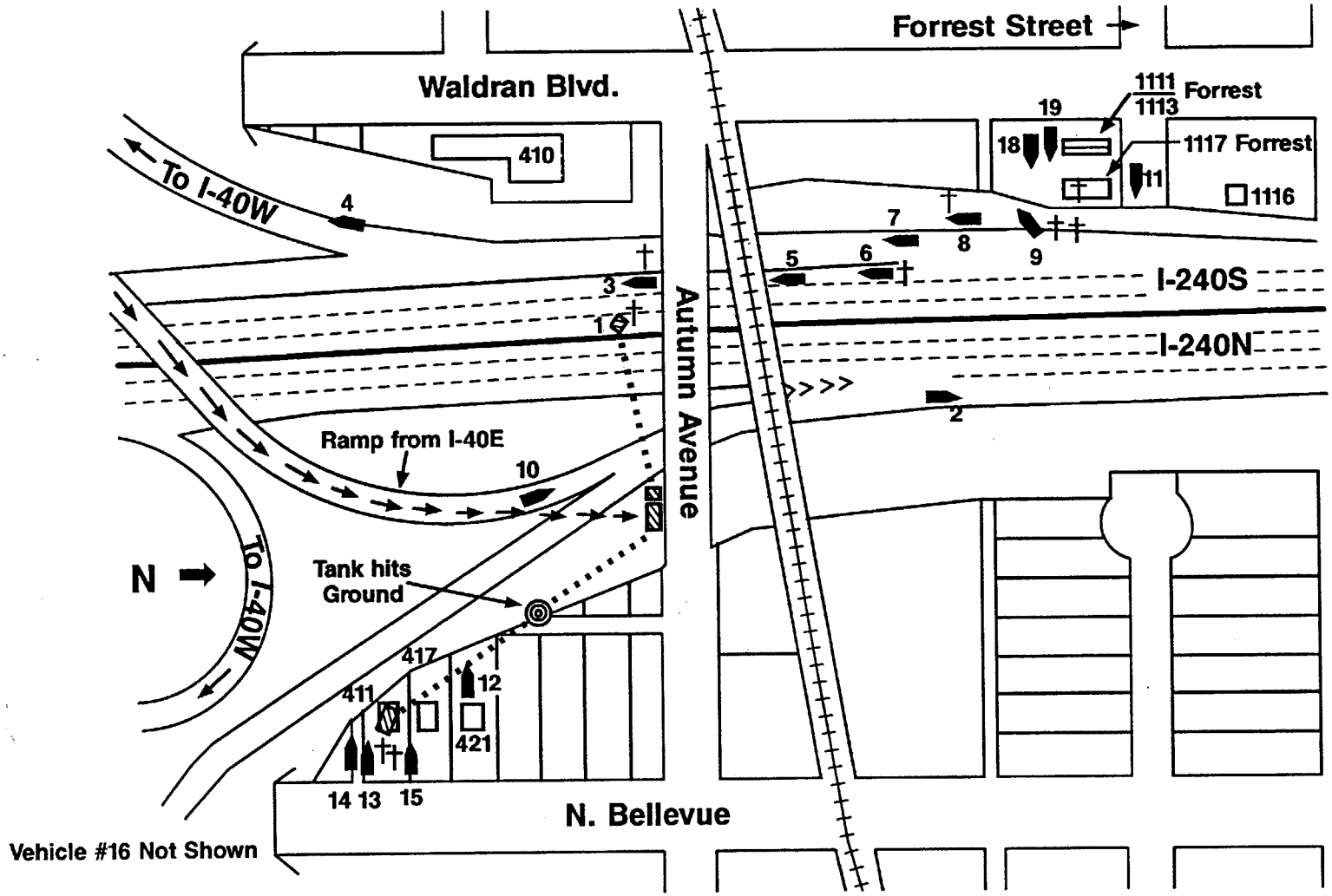

Figure 2: Accident Site and Vehicle Locations

- Travel path before explosion
- Travel of tank and tractor after explosion
- Tractor and trailer before BLEVE
- Tractor after BLEVE
- Propane tank after BLEVE
- Private Vehicles
- † Approximate location of fatalities