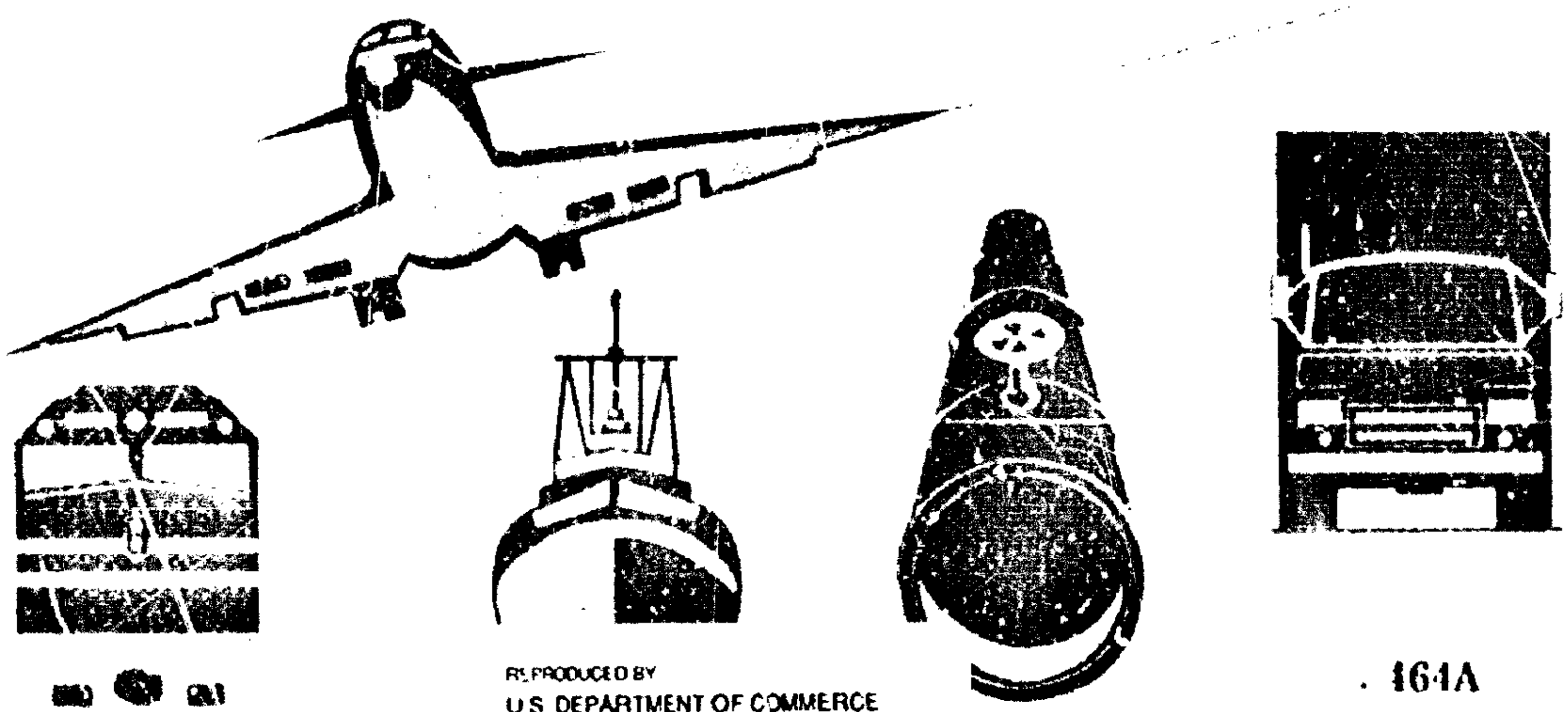
PB92-916202
NTSB/HAR-92/02

NATIONAL TRANSPORTATION SAFETY BOARD

WASHINGTON, D.C. 20594

HIGHWAY ACCIDENT REPORT

MULTIPLE-VEHICLE COLLISIONS AND FIRE DURING LIMITED VISIBILITY (FOG) ON INTERSTATE 75 NEAR CALHOUN, TENNESSEE DECEMBER 11, 1990



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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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WASHINGTON, D.C. 20594

HIGHWAY ACCIDENT REPORT

ADOPTED: September 28, 1992

NOTATION 5464A

Abstract: About 9:10 a.m. on December 11, 1990, during fog on Interstate 75 near Calhoun, Tennessee, 99 vehicles were in multiple-vehicle chain-reaction collisions that killed 12 people and injured 42 others.

The safety issues discussed in this report are nonuniform driver behavior during limited-visibility conditions, detection of limited-visibility conditions, limited-visibility countermeasures, and hazardous materials container performance.

As a result of its investigation, the Safety Board made recommendations addressing these issues to the United States Department of Transportation; the Federal Highway Administration; the National Highway Traffic Safety Administration; the Tennessee Department of Transportation; the Tennessee Highway Patrol; the American Association of Motor Vehicle Administrators; the Research and Special Programs Administration; Hercules, Incorporated; the Charleston Volunteer Fire Department; the American Automobile Association; and the American Driver and Traffic Safety Education Association.

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EXECUTIVE SUMMARY

About 9:10 a.m. on December 11, 1990, a tractor-semitrailer in the southbound lanes of I-75 near Calhoun, Tennessee, struck the rear of another tractor-semitrailer that had slowed because of fog. The uninjured truckdrivers exited their vehicles and attempted to check for damage. After the initial collision, an automobile struck the rear of the second truck and was in turn struck in the rear by another tractor-semitrailer. Fire ensued and consumed two trucks and the automobile. Meanwhile, in the northbound lanes of I-75, an automobile struck the rear of another automobile that had slowed because of fog. Then, a pickup truck and two other automobiles became involved in the chain-reaction rear end collision. No fatalities, injuries, or fires occurred. Subsequently, 99 vehicles in the northbound and southbound lanes were in multiple-vehicle chain-reaction collisions that killed 12 people and injured 42 others.

The National Transportation Safety Board determines that the probable cause of the multiple-vehicle collisions on I-75 near Calhoun, Tennessee, was drivers responding to the sudden loss of visibility by operating their vehicles at significantly varying speeds.

The safety issues discussed in this report include:

- Nonuniform driver behavior during limited-visibility conditions.
- Detection of limited-visibility conditions.
- Limited-visibility countermeasures.
- Hazardous materials container performance.

As a result of its investigation, the Safety Board made recommendations addressing these issues to the United States Department of Transportation; the Federal Highway Administration; the National Highway Traffic Safety Administration; the Tennessee Department of Transportation; the Tennessee Highway Patrol; the American Association of Motor Vehicle Administrators; the Research and Special Programs Administration; Hercules, Incorporated; the Charleston Volunteer Fire Department; the American Automobile Association; and the American Driver and Traffic Safety Education Association.

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MULTIPLE-VEHICLE COLLISIONS AND FIRE DURING LIMITED VISIBILITY (FOG) ON INTERSTATE 75 NEAR CALHOUN, TENNESSEE DECEMBER 11, 1990

INVESTIGATION

The Accident

About 5:30 a.m. on December 11, 1990, a Tennessee Highway Patrol (THP) trooper conducted a routine fog check on Interstate (I) 75[1] near Calhoun, Tennessee; he found no fog. While commuting to work at 8:15 a.m., a THP captain drove through the same area and noticed a light fog that caused him no visibility problems. About 9 a.m., motorists traveling in the southbound and northbound lanes of I-75 observed light fog that became dense as they approached the Lamontville Road (State Route [SR] 163) overpass near Calhoun. Southbound drivers reported fog about 1 1/2 miles north of milepost (MP) 36 (accident site). The estimated sight distance at MP 36 was 20 feet. Northbound drivers reported first sighting fog at MP 32 about 4 miles south of the accident site. Some drivers reported that as they progressed into the dense fog, their sight distance dropped to 10 feet or less.

About 9:10 a.m., while traveling 35 to 40 mph, a southbound tractor-semitrailer transporting dicumyl peroxide[2] in portable tanks struck the rear of a 1990 Freightliner tractor-semitrailer that had slowed to about 25 mph because of the fog. This collision occurred about 100 feet south of the SR 163 overpass. Three to 5 minutes elapsed while the uninjured truckdrivers exited their vehicles and attempted to check for damage.

After the initial collision, a 1991 Oldsmobile Delta 88 4-door sedan struck the rear of the dicumyl peroxide truck; a 1989 Freightliner tractor-semitrailer in turn struck the rear of the Oldsmobile and crushed it beneath the dicumyl peroxide truck. Fire ensued and consumed these two trucks[3] and the Oldsmobile, whose driver and passenger were killed. No other injuries occurred in the first multiple-vehicle chain-reaction collision (accident cluster). Additional chain-reaction collisions subsequently occurred in the southbound lanes. Accident clusters involving 72 southbound vehicles extended about 1/5 mile north of the SR 163 overpass. (See figures 1 and 2 and appendix B.)

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[1] Tennessee Department of Transportation (TDOT) officials identified a fog-prone area on I-75 north and south of the Hiwassee River in the Tennessee Valley about 30 miles north of Chattanooga, Tennessee.

[2] A flammable organic peroxide used to modify plastic to improve its resistance to heat.

[3] The 1990 Freightliner was operable, uneffected by the fire, and later driven from the accident scene

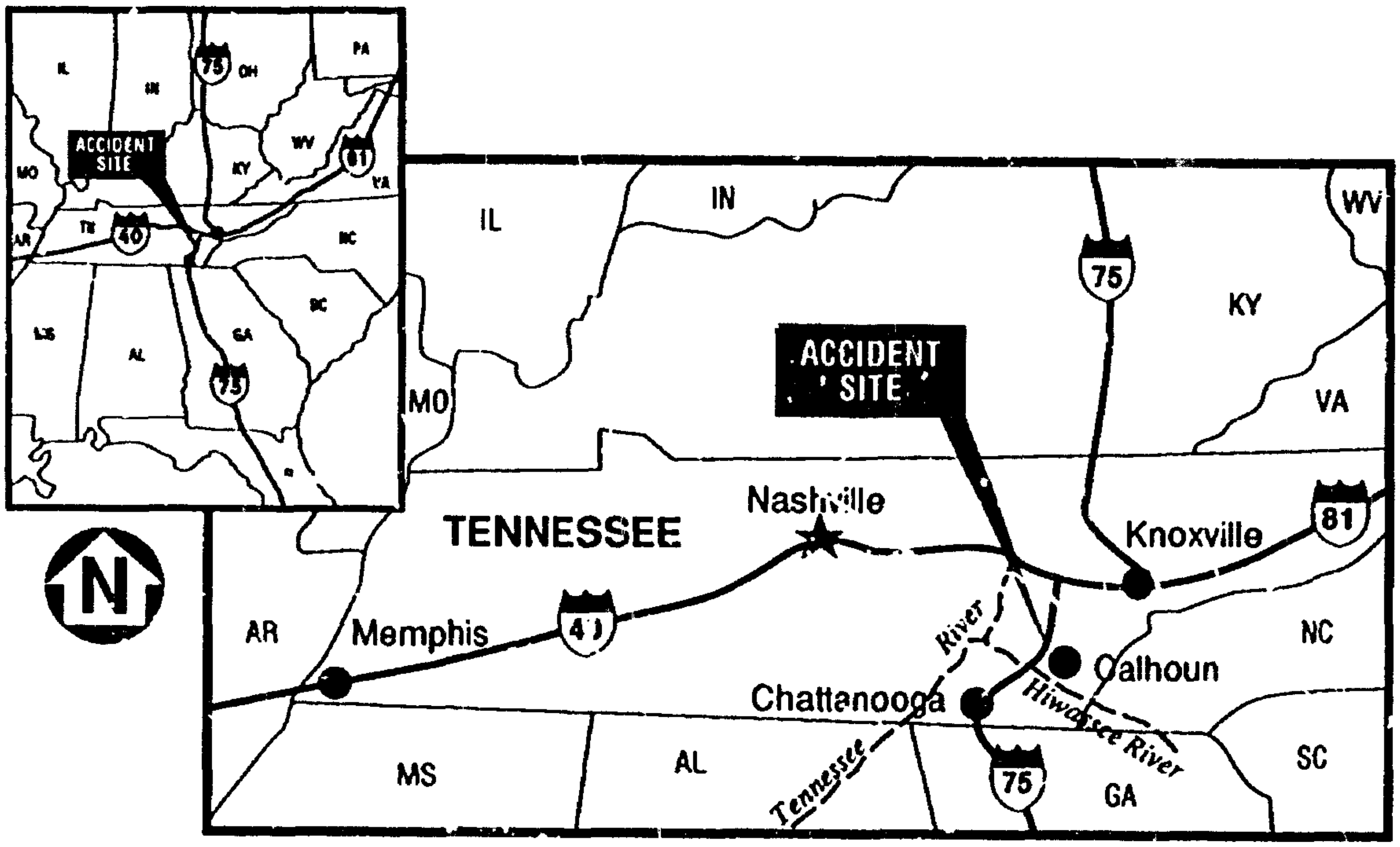

Figure 1.--Map of accident site.

About 9:15 a.m., a 1987 Ford Escort northbound on I-75 near the SR 163 overpass struck a 1987 Honda four-door sedan that had slowed due to the limited visibility. A 1982 Toyota pickup truck subsequently struck the rear of the Escort, a 1990 two-door Pontiac struck the rear of the Toyota, and a 1989 Oldsmobile Delta 88 struck the rear of the Pontiac. No fatalities, injuries, or fires occurred in this accident cluster. Additional chain reaction collisions occurred in the northbound lanes, and eventually, accident clusters involving 27 northbound vehicles extended about 1/4 mile south of the SR 163 overpass. (See appendix B.)

At 9:15 a.m., a southbound driver in a radio-equipped car reported the accident involving the 1991 Oldsmobile and 1989 Freightliner to her dispatcher, who notified the McMinn County emergency communications center. The McMinn County and Bradley County officials activated their disaster plans and emergency operations centers; the counties' fire and rescue officials coordinated firefighting, rescue, and hazardous materials activities. About 9:30 a.m., the Tennessee Emergency Management Agency (TEMA) was notified of the accident and responded to coordinate Federal, State, and local authorities.

At 9:32 a.m., the THP closed the northbound lanes near MP 33; at 9:34 a.m., the McMinn County Sheriff's Department closed the southbound lanes near MP 42. The THP reopened one northbound lane by 2:43 p.m.; the southbound lanes were reopened at 7:35 p.m. on December 12.

Figure 2 Aerial photograph I-75 southbound lanes
Courtesy of Nicholas Arroyo, The Atlanta Journal and Constitution

Because cleanup operations and reopening the highway prevented the Safety Board from reconstructing the accident, investigators used police reports, witness statements, videotapes, and aerial photographs to develop the accident scenarios. (See figure 3 and appendix C.)

Injuries

Safety Board Injury Table[4]

Injuries	Drivers	Passengers	Total
Fatal	9	3	12
Serious	12	7	19
Minor	17	6	23
Total	38	16	54

Driver Information

The Safety Board received the following responses to a questionnaire sent to 99 drivers who were involved in this accident.

	Drivers
Questionnaire responses	56
Long-distance travelers	35
Local commuters	21
Familiar with road during local weather conditions	43
Unfamiliar with road during local weather conditions	13
Headlights on	49
Flashers on	10
Other vehicle headlights seen	23
Fog warning signs seen	48
Beacons on fog warning signs flashing	25
Beacons on fog warning signs not flashing	17
Fog warning signs/flashing beacons not seen	28
Left lane before accident	13
Right lane before accident	40
Windshield wipers on	21
Windshield wipers helpful	6
Struck vehicle in front	11
Rear ended, while slowed or stopped	16
Pushed into vehicle in front, while stopped	8
Struck vehicle in front, then rear ended	15
No collision	4
Speed between 15 and 50 mph entering fog	18
Speed between 55 and 70 mph entering fog	37
Vehicle equipped with high-mounted stoplight	15

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[4]This injury table is based on the injury criteria of the International Civil Aviation Organization, which the Safety Board uses in accident reports for all transportation modes. An injury table based on the Abbreviated Injury Scale (AIS) of the American Association for Automotive Medicine is in appendix E

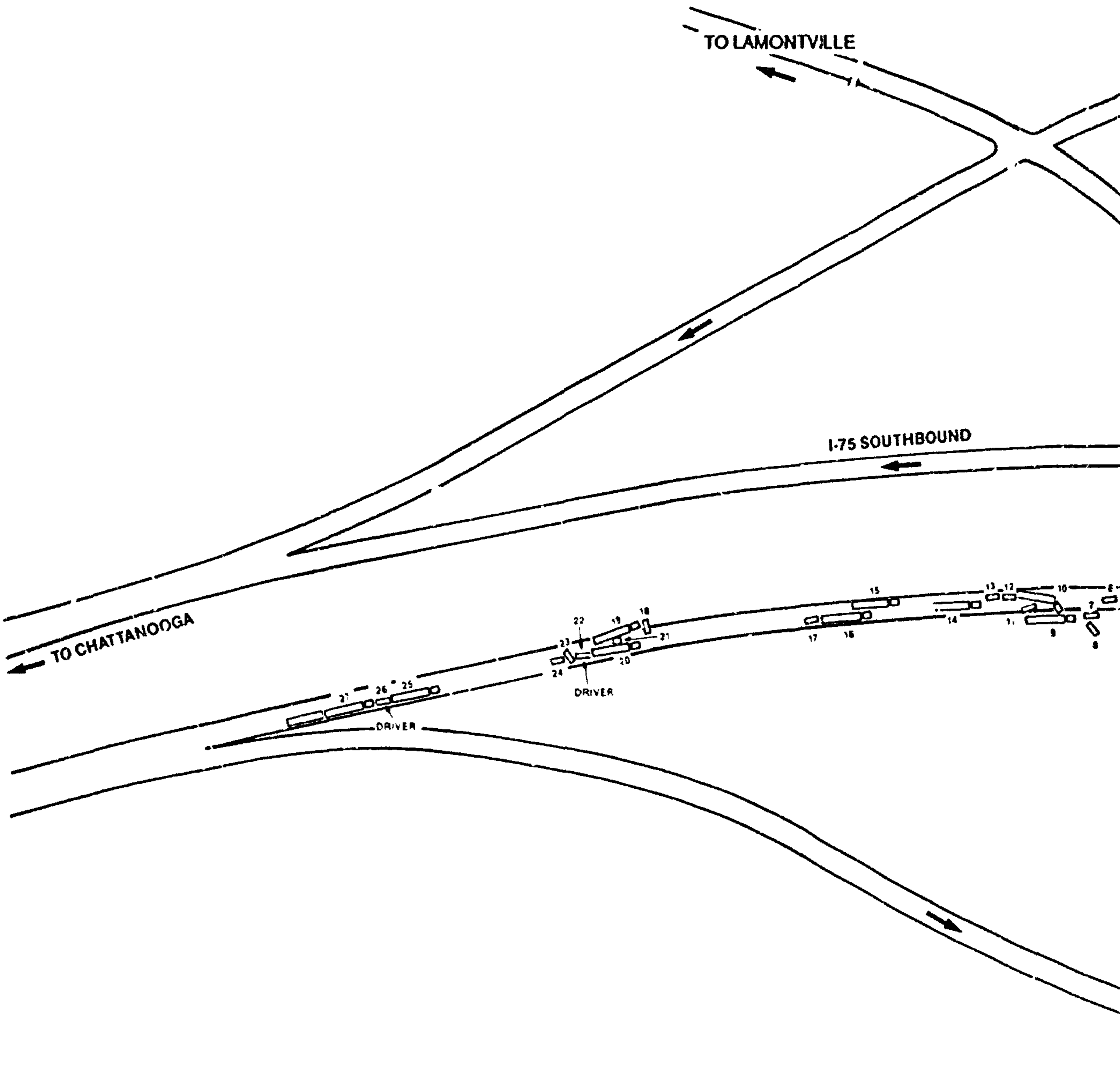
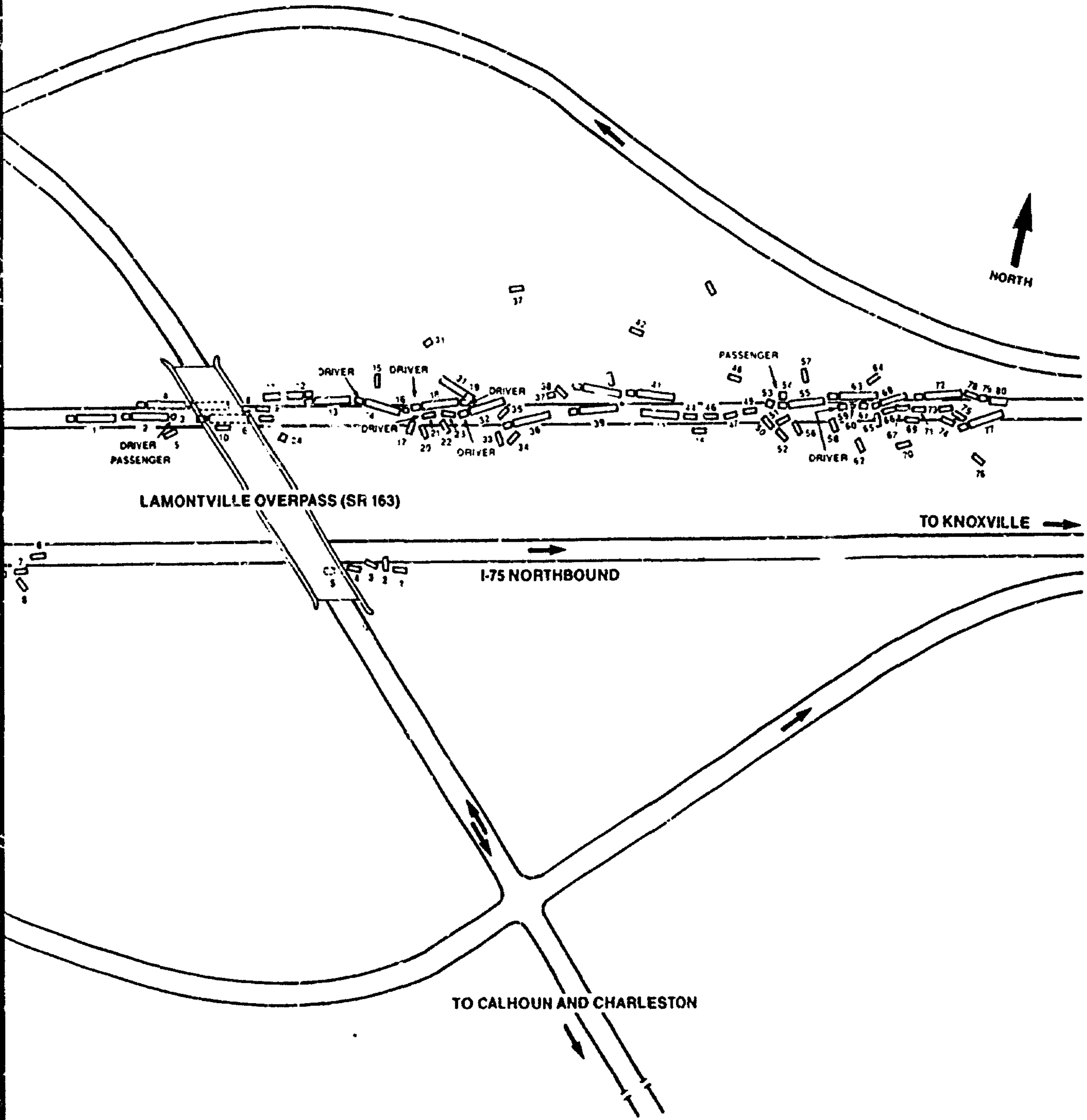


Figure 3. Postaccident location of vehicles.

Not to Scale. Vehicles in relative positions.
Not all vehicles shown on diagram; appendix C lists vehicles shown. Fatally injured persons are also indicated.



NORTH
PASSENGER
DRIVER
DRIVER
DRIVER
DRIVER
DRIVER
DRIVER
DRIVER
PASSENGER
LAMONTVILLE OVERPASS (SR 163)
TO KNOXVILLE
I-75 NORTHBOUND
TO CALHOUN AND CHARLESTON

Vehicle Information

The following vehicles were in accident clusters.

	Totals
Tractor-semitrailer combinations	24
Straight body trucks	6
Pickup trucks	16
Motor homes	3
Vans/special use	8
Automobiles	42
Total	99

Highway Information

Opened in December 1973, I-75 is a four-lane, north-south, limited-access highway through eastern Tennessee. The accident occurred about 1 mile north of the Hiwassee River, which separates McMinn County from Bradley County. Within a 5-mile radius of the accident site are the Bowater, Inc., paper mill, the Olin Corporation chemical processing plant, the Cleveland Municipal Utilities wastewater treatment plant, a salt storage facility, several rural communities, and numerous rivers, creeks, and lakes.

Approaching the accident site, the northbound lanes have less than 1-percent downhill grade from the Hiwassee River bridge to about 190 feet before the SR 163 overpass. The northbound and southbound lanes are parallel; they curve slightly between the Hiwassee River and the SR 163 interchange, where they become tangent and remain so through the accident site. The posted speed limit is 65 mph.

The road has an asphaltic concrete surface, which was dry at the time of the accident. The cross section consists of two 12-foot-wide lanes with 12-foot-wide outside shoulders and 6-foot-wide inside shoulders in each direction. A 150-foot-wide grass median separates the northbound and southbound lanes. The centerline lane markings are 12-foot-long white thermoplastic strips at 28-foot intervals with retroreflective pavement markers (RRPMs) at 20-foot intervals. The median yellow edge line and the outside white edge line are solid. Diagonal thermoplastic strips, each with five RRPMs, are at 45-foot intervals on the outside shoulders. RRPMs are at 40-foot intervals on the left edge lines, and delineator posts are at 90-foot intervals on the outside shoulder edge. (See figure 4.)

Fog warning signs are at MP 37.5 for the southbound lanes and at MP 31.6 for the northbound lanes. (See figures 5 and 6.) The yellow, 6- by 12-foot signs marked in black letters EXTREME DENSE FOG AREA NEXT 5 MILES are on each side of both lanes and have a yellow flashing beacon at each top corner. A THP trooper can manually activate the beacons at a switch box on the sign support post. The THP reported that the southbound beacons had been activated 3 days before the accident and had not been turned off. The northbound beacons were not on immediately before or during the accident.

The average daily traffic count on I-75 was 13,040 in 1975, 28,950 in 1989, and 28,060 in 1990. The 1989 classification counts indicated that about 30 percent of the vehicles were trucks. An October 1990 weekday count recorded that between 9 and

Figure 4.--South view of the northbound lanes

Figure 5.--Southbound fog warning sign

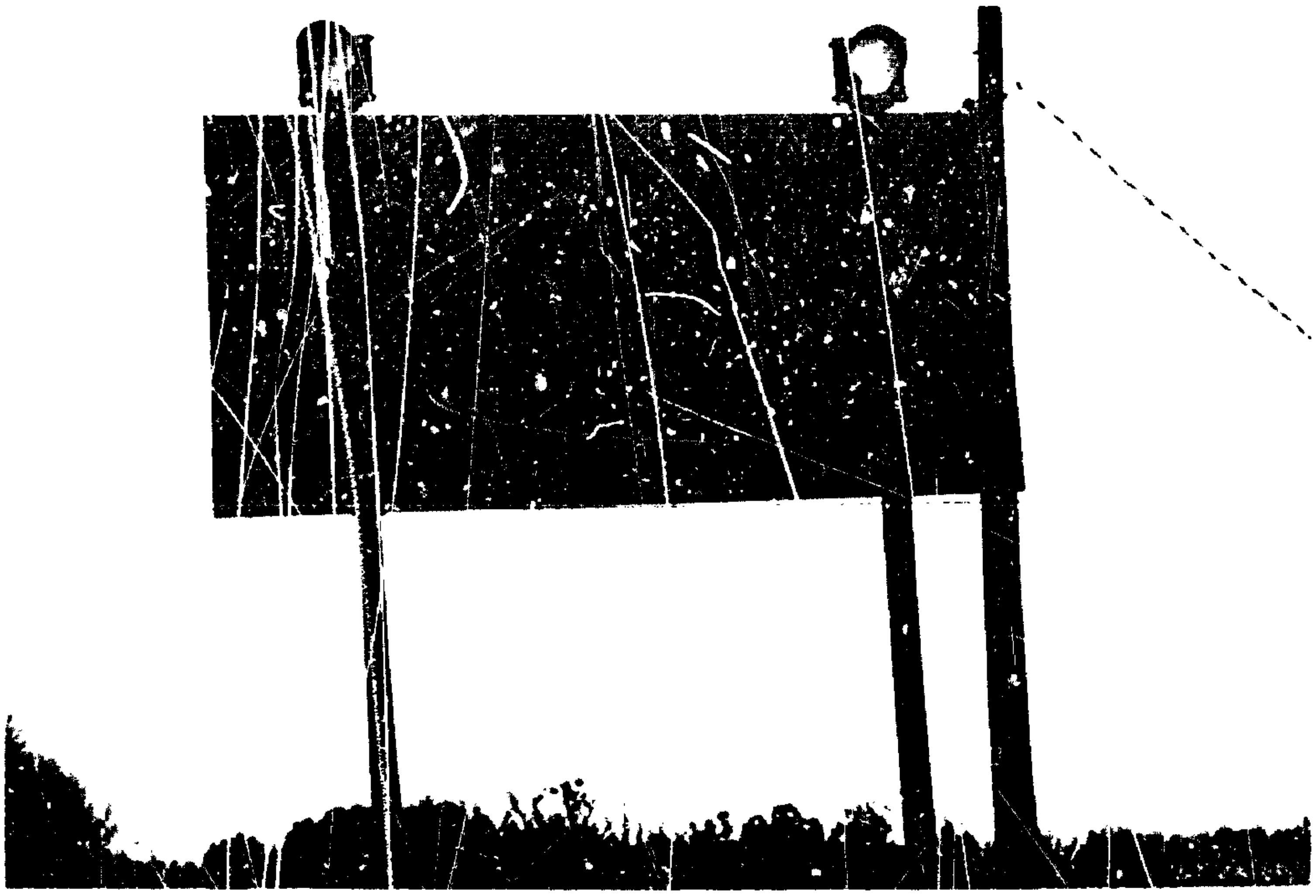


Figure 6.--Northbound fog warning sign.

10 a.m., the southbound lanes carried 786 vehicles and the northbound lanes carried 617 vehicles.

Postaccident Site Examination

As a result of the collisions, the road surface was covered with fuel, other liquids, and debris. Firefighters used a special absorbent material to remove the liquids. The recovery and salvage equipment made numerous scrape and gouge marks on the road surface that were unrelated to the accident. (See figure 7.)

State officials removed the accident vehicles without measuring distances or marking vehicle positions on the road for future reference. Although postaccident photographs were taken at the accident site, vehicles were not categorized for damage comparisons after removal. Removal of the vehicles expedited rescue, recovery, and salvage operations and reopening of the highway; however, it precluded the Safety Board from collecting some information necessary for a complete accident reconstruction. Investigators were able to determine through witness interviews that no vehicle operators unintentionally drove off the road.

Meteorological Information

The National Weather Service (NWS) forecast for the Calhoun area was prepared at its Memphis, Tennessee, forecast office. At 5:20 a.m. on December 11,

Figure 7.--Postaccident cleanup in the southbound lanes

1990, the forecast was "Today . . sunny and mild. High in the mid 60's. Wind variable 5 mph." Fog was not forecast and did not occur in most of the forecast area. The NWS offices at Lovell Airport in Chattanooga, Tennessee, and the McGhee Tyson Airport in Knoxville, Tennessee,[5] reported clear skies, light-to-calm winds, and unrestricted visibility from 6 to 10 a.m.

Local Conditions.--The Sequoyah nuclear power plant is about 18 miles west-southwest of the accident site, and the Watts Bar nuclear power plant is about 19 miles north of the accident site. Both facilities have towers equipped with weather recording instruments that measure temperature at elevations of 32.8 feet, 150.9 feet, and 298.5 feet above grade. Between 6 and 10 a.m. on December 11, the equipment recorded a temperature increase with height, indicating a temperature inversion.[6] Fog was also reported.

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[5]Lovell Airport is about 30 miles southwest and McGhee-Tyson Airport is about 57 miles northeast of the accident site.

[6]Under normal conditions, the atmospheric temperature decreases with height. A temperature increase, an inversion, indicates a stable (calm) atmosphere. The vertical dispersion of moisture, gases, and particulates in the air is diminished, which leads to stratified concentrations near the surface.

During the night of December 10 and the early morning hours of December 11, near equilibrium existed between the water removed from the air by the deposition of dew and frost on land and vegetation and water added to the air by evaporation from water surfaces The sources of water were the Hiwassee River, Lake Chickamauga (including North and South Mouse Creeks), the Cleveland wastewater treatment plant, the Bowater aerators,[7] the Bowater and Olin treatment ponds, and stack[8] gases.

Postaccident aerial photographs taken about 10 a.m. show fog in the I-75 valley and adjacent valleys, smoke from the burning dicumyl peroxide truck, and vapor plumes rising from the Bowater facility. (See figures 8 and 9.)

Bowater Facility Observations.--Located about 2 miles southeast of the accident site, Bowater routinely collects selected weather data at its three remote automated weather recording stations. Bomet is 1.85 miles northwest, Bonorth is 0.7 mile northeast, and Bosouth is 1 mile south of the plant's center. (See figure 10.)

During the evening of December 10, Bowater equipment recorded the dew point[9] at or slightly above the overnight minimum temperature, indicating air saturated with water vapor. On December 11, equipment recorded 29.8 °F at 7 a.m. and 38.3 °F at 10 a.m. The relative humidity [10]readings were 95 percent at 6 a.m. and 100 percent at 9 and 10 a.m. Between 7 and 7:30 a.m., Bowater personnel observed dense fog at Bomet.

From 6 to 9 a.m., the average winds at Bomet, Bonorth, and Bosouth were, respectively, from the northwest at 1.2 mph, from the northeast at 1.8 mph, and from the southeast at 1.3 mph. (See figure 10.) Between 9 and 10 a.m., Bomet recorded an increase in wind speed to 1.8 mph.

In its manufacturing operation,[11] Bowater uses four wastewater storage-treatment ponds (see figure 10) to meet its national pollution discharge elimination system permit requirements. On December 11, Bowater personnel recorded 50 °F for the Hiwassee River and water treatment pond #4.[12] At the Safety Board's request, Bowater personnel recorded the temperatures in the storage ponds on December 12. The wastewater entering ponds #1, #2, #3, and #4 was 102 °F, 88 °F, 81 °F, and 68 °F, respectively.

Olin Facility Observations.--Located about 1.2 miles south of the accident site, the Olin facility also routinely collects selected weather data. At 1 30 a.m on December 11, its equipment recorded a 38 °F temperature, and personnel observed

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[7]To expedite biodegradation of organic materials, aerators oxygenate water by spraying it into the air before it collects in the treatment pond

[8]Bowater stacks are about 200 feet and Olin stacks are about 100 feet above the surface

[9]The temperature at which moisture condenses on surfaces

[10]Relative humidity is the percentage of water vapor saturation at a given temperature The quantity of moisture that produces 50 percent humidity a [illegible]3 °F will yield 90 percent humidity at 50 °F

[11]Bowater removes water from the Hiawasee River. This water is incidentally heated during the manufacturing process. It is cleaned and cooled in the treatment ponds before its return to the river

[12]Water treatment is measured in the storage ponds to determine the efficiency of bacteria removal from the water.

Figure 8.--Aerial photograph of Calhoun area

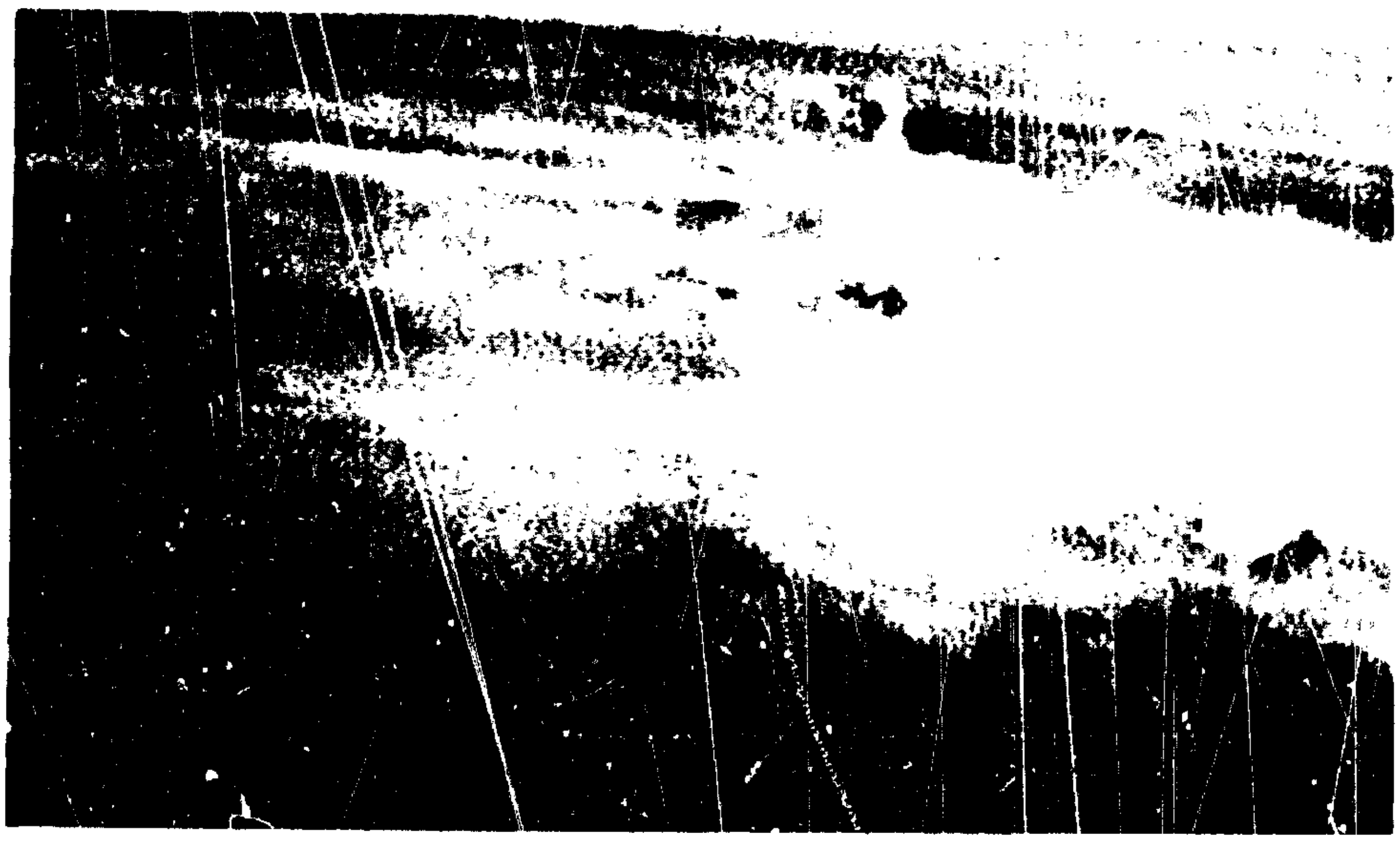
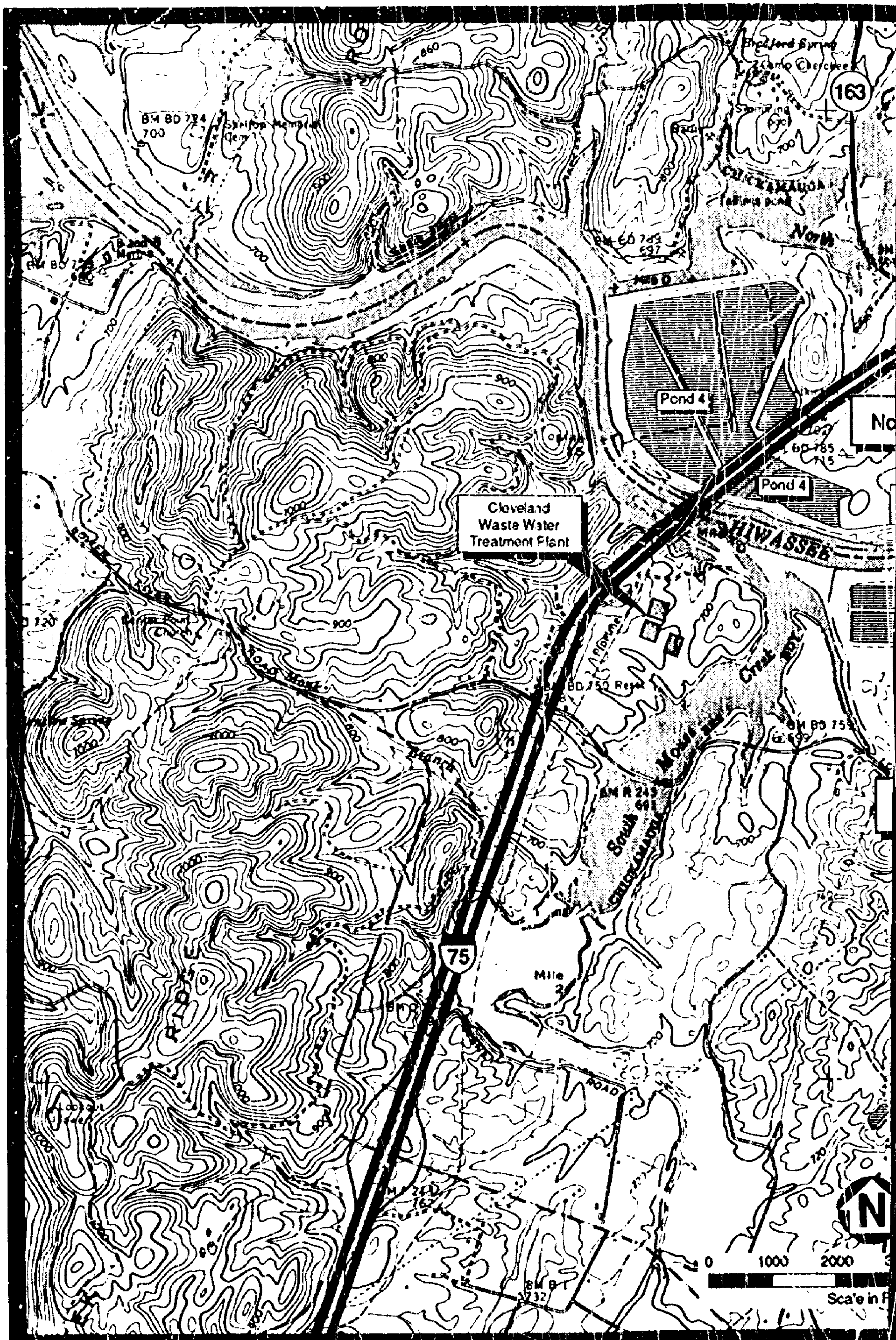


Figure 9.--Aerial photograph of stack emissions at the Bowater facility



Cleveland
Waste Water
Treatment Plant
Pond 4
Pond 4
HIWASSEE
163
75
0 1000 2000

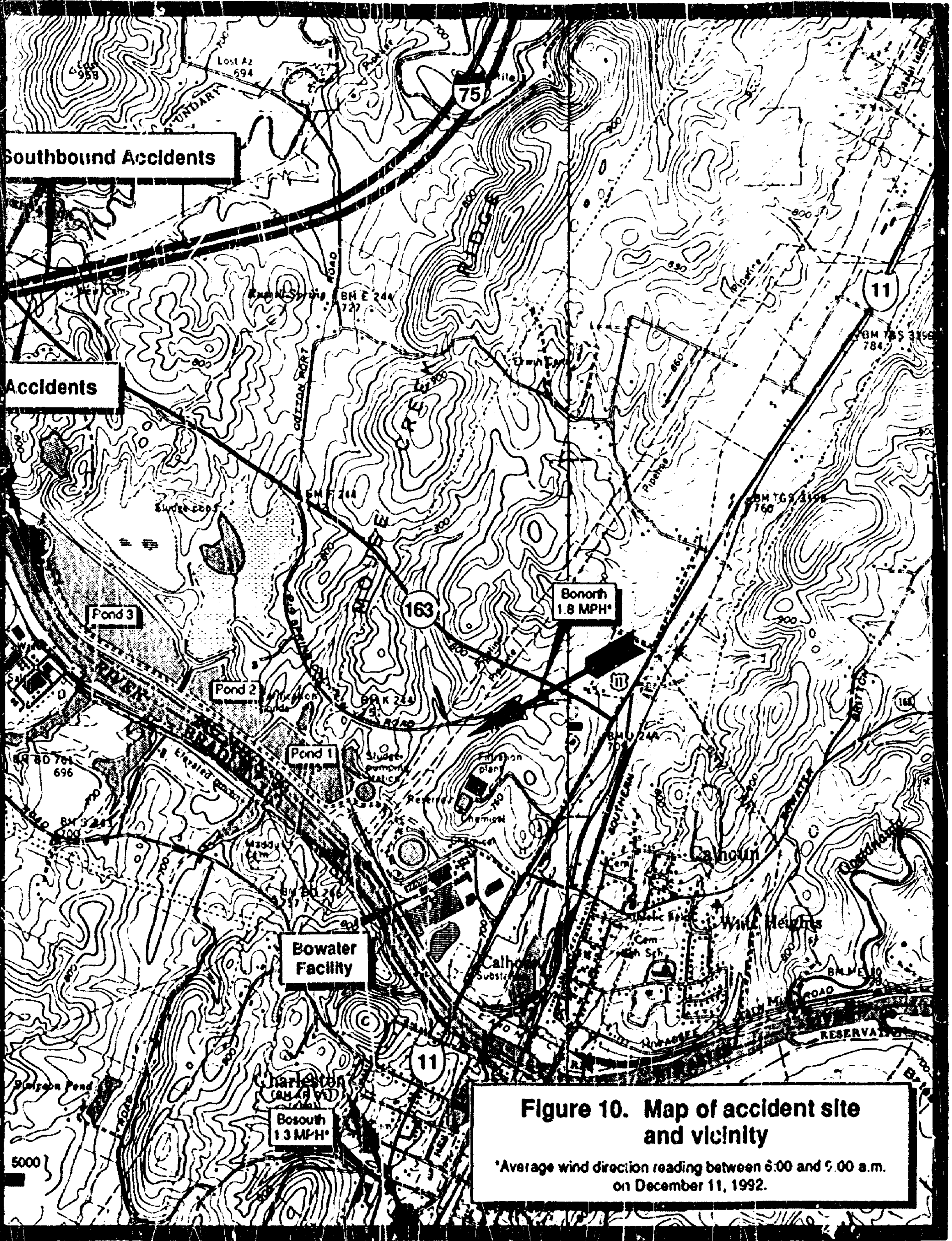


Figure 10. Map of accident site and vicinity

*Average wind direction reading between 6:00 and 9:00 a.m. on December 11, 1992.

dense fog. At 5:30 a.m., the temperature was 38 °F and fog was still observed; at 9:30 a.m., the temperature was 35 °F and dense fog continued.

The Olin facility received data from an anemometer.[13] Between 6:15 and 9:10 a.m., no wind speed was recorded,[14] and the wind direction varied between south-southwest and west. Between 9:10 and 9:45 a.m., the recorded wind speed was about 5 mph, and the wind direction varied between south-southwest and west. The predominant direction was west-southwest.

Medical, Pathological, and Toxicological Information

The assistant medical examiner from McMinn County determined that the victims died accidentally and established a probable cause of death through external examination only. Eight victims died as a result of fire and its effects; three victims died from massive trauma; and one victim suffered a fractured neck.

The injuries sustained by survivors ranged from minor bruises and abrasions to critical traumatic injuries. The injured were treated at hospitals in Athens, Cleveland, Chattanooga, and Knoxville, Tennessee. One of the three State troopers who reported eye irritation was also treated at a hospital.

The driver of the dicumyl peroxide truck voluntarily provided blood and urine specimens, which were tested at the National Psychopharmacology Laboratory, Inc., in Knoxville and the community hospital in Cleveland. No alcohol or impairing drugs were detected.

Emergency Response

After receiving notification of the accident about 9:15 a.m., the McMinn County and Bradley County sheriff's departments and the Athens and Cleveland police departments dispatched units. A THP unit patrolling SR 163 about 1 mile east of I-75 also responded. Subsequently, on I-75 about 7 miles south of the accident scene, a motorist alerted another THP trooper. At 9:18 a.m., four McMinn County fire and rescue units and the Riceville and Calhoun fire departments were dispatched.

About 9:30 a.m., McMinn County Emergency Medical Services (EMS) staff established a triage area on the median north of the SR 163 overpass. The McMinn County EMS Director, who is a physician, supervised the triage operations. The medical mobile command post and ambulance staging area were established on the shoulder of the highway. The Bradley County EMS staff established a triage area on the southbound road near the helicopter landing zone south of the SR 163 overpass. The Bradley County EMS Director, who is also a physician, supervised the triage operations there.

Hazardous Materials

Firefighter Response.--About 9:30 a.m., the Charleston Volunteer Fire Department arrived, and firefighters found a burning vehicle in the southbound

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[13]An instrument that records wind velocity.

[14]The Olin anemometer has a recording threshold of 5 mph; consequently, any wind movement below this threshold will not be measured. The Bowater anemometer has a lower recording threshold.

lane about 25 feet south of the SR 163 overpass. The Charleston firefighters stated that they observed burning containers on the rear of a semitrailer and that they used water to try to extinguish the 30- to 40-foot-high flames. The Charleston firefighter-in-charge, who had some training in fighting fires that involved hazardous materials, did not realize that a hazardous material was involved until the dicumyl peroxide fire was out.

Since the accident, 11 of the Charleston Volunteer Fire Department's 30 members have received training in recognition of and response to hazardous materials fires. Three of the department's firefighters had received such training before the accident. None of its members are full-time or salaried employees.

Because of the presence of propane and liquid nitrogen cargo tanks involved in the accidents, a hazardous materials unit from the Cleveland/Bradley County Emergency Management Agency responded to the accident scene. About 9:40 a.m., the Cleveland/Bradley County Emergency Management Agency established an incident command post at MP 36 near the southbound lanes. The agency's assistant chief and his team determined that the vehicles transporting propane and liquid nitrogen were not leaking. At 9:53 a.m., the assistant chief was informed that a vehicle transporting unknown chemicals was burning in the southbound lanes near the SR 163 overpass. At the fire scene, the assistant chief and a THP trooper located the truckdriver, who said that his cargo was 10 stainless steel bulk tanks of "organic peroxide UN2121."[15] A witness later reported that about 9:50 a.m., the lids blew off the dicumyl peroxide tanks, and "fire balls" shot 20 to 40 feet above the overpass. The assistant chief advised the incident command post about 10:15 a.m. that he and the Charleston firefighter-in-charge had decided to let the fire burn itself out and to concentrate the firefighting effort on control and containment. The fire was out at 11:37 a.m.

Chemicals and Transportation.--Three tractor-semitrailers transporting hazardous materials were in collisions: two in the northbound lanes and one in the southbound lanes.

The northbound semitrailers were cargo tanks, one of which held about 10,000 gallons of liquefied propane (flammable gas) and the other about 6,000 gallons of liquefied nitrogen (nonflammable gas). Neither tank was breached; the nitrogen vented through tank safety valves, as designed, to relieve pressure.

The southbound semitrailer carried 10 portable tanks.[16] Each held about 400 gallons of dicumyl peroxide[17] and weighed about 4,300 pounds filled. Transported in a granular, crystalline form, dicumyl peroxide is heated, until it liquefies at 100 °F, to fill and to empty the tanks. Above 240 °F, an extremely rapid, self-accelerating decomposition occurs that results in release of heat. When this chemical reaction takes place, dicumyl peroxide changes from liquid to gaseous state, resulting very quickly in a large increase in pressure in an enclosed space, such as a tank. Flammable gases, including methane and ethane, are released during this reaction

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[15]U.S. Department of Transportation (DOT) identification number for dicumyl peroxide

[16]The tanks were designed, owned, filled, and shipped by Hercules, Incorporated, Wilmington, Delaware.

[17]Manufactured by Hercules, Incorporated, dicumyl peroxide is an organic peroxide relatively stable at room temperatures

and, together with other products of decomposition, may cause eye, skin, and respiratory irritation. Water, dry chemicals, or carbon dioxide are recommended for extinguishing a dicumyl peroxide fire.

Designed and constructed to DOT specification 57 (DOT 57), each stainless steel portable tank carried up to 460 gallons and weighed about 750 pounds empty. To lift and move the tanks, stainless steel fork lift channels had been welded to each tank bottom; they also supported the tank. A 3 1/4-inch diameter plastic closure that provided double the pressure-relief venting capacity required by regulation was installed in the steel lid of each tank. The plastic closures acted as fusible pressure-relief devices and were designed to function between 260 and 290 °F.[18] Each 22 1/2-inch diameter steel lid was designed to pop off at 15 to 20 psi as an additional pressure-relief system to prevent rupture of the tank.

Hercules believed that the 3 1/4-inch diameter pressure-relief opening was not sufficient to relieve pressure within the container during a rapid decomposition reaction. Hercules found during tests that containers with a 22 1/2-inch diameter pressure vent opening experienced internal pressures between 140 and 247 psi during rapid decomposition of dicumyl peroxide. Hercules calculated that the portable tanks without the larger vent openings would burst at 247 psi because the internal pressure created during a rapid decomposition reaction would exceed the structural strength of the tank. Therefore, Hercules designed the 22 1/2-inch lid as a pressure-actuated-relief system to prevent an overpressure rupture of the tank and installed the 3 1/4-inch diameter plastic closure to meet regulatory requirements.

Postaccident examination disclosed that eight tanks had no lids attached. Of the two tanks with secured lids, one had a puncture through the tank wall, and the other was found lying on its side. The plastic closures were missing from all lids. (See figure 11.)

Postaccident examination of the portable tanks revealed that 3 of the 10 tanks had punctures corresponding to the size and shape of the fork lift channels on the base of other units. The examination also disclosed soot and heat damage patterns consistent with exposure to fire. The fracture surfaces at the tank puncture locations were also covered with a layer of soot that was nearly identical to the soot patterns found on the outside surface of the tank walls adjacent to the puncture.

Other Information

National Data.--In 1989, 1990, and 1991, deaths on interstate roadways when fog was present numbered 103, 84, and 67, respectively. During the same years, 783, 718, and 667 people were killed on all classes of roads when fog was present. (See appendix F for data table.)

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[18]Title 49 Code of Federal Regulations 173.154(a)(3) requires fusible pressure-relief devices installed in DOT 57 portable tanks that transport dicumyl peroxide to function between 158 and 194 °F

Figure 11.--The dicumyl peroxide tanks at the accident scene

Fog Formation.--Fog is a mass of minute water particles suspended in the air near the surface of the earth. For fog to form, two factors are necessary: a saturated atmosphere and a surface (condensation nuclei)[19] on which moisture can condense.

The atmosphere may become saturated by the addition of water to the air until minute water droplets form or by the reduction of air temperature until it reaches the dew point. The amount of water vapor that the air can hold is a function of temperature: at 32 °F, 50 °F, 68 °F, and 86 °F, the air is saturated at 0.4-percent, 0.8-percent, 1.5-percent, and 2.8-percent water vapor, respectively.

The most prevalent fog, radiation fog, typically forms over a land area when radiation cooling reduces the air temperature to its dew point. On clear nights, the earth's surface readily loses its heat to space by radiation, thereby cooling the surface. The cooler surface in turn cools the air adjacent to it, creating a surface inversion in which cooler, dense air is trapped beneath warmer, less dense air. Inversions associated with radiation fog are frequently 100 to 300 feet thick.

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[19] Particles such as dust from dry ground, salt from the ocean, ash from fires, organic material from decaying vegetation, exhaust from automobiles, smoke from home and commercial heating, and products from industrial processes.

In a valley, the formation and density of radiation fog can be enhanced by air cooled by contact with surrounding hills that moves downhill, further cooling air on the valley floor; by moisture added to the air from a water source, such as a river, lake, or pond; or by condensation nuclei added to the atmosphere from industrial operations, fossil fuel burning, or vehicular emissions.

Radiation fog can develop very quickly when the atmosphere is mixed by air movement at 4 to 7 mph; when the wind exceeds 9 mph, the fog is lifted to become a low cloud layer that does not restrict surface visibility. Fog frequently forms shortly after sunrise when the sun's initial heat causes a light surface wind and is dispersed later by the sun's intense heat as it warms the earth surface and lifts the fog.

During winter months, steam fog is common over lakes, rivers, and bays in the United States. It occurs when cool air is over a body of comparatively warm water and evaporating moisture from the warm water saturates the lower levels of the cool air. The vapor condenses in small convective columns near the water surface and gives the appearance of smoke or steam.

Water Sources Near Accident Site.--About 1,159 acres of natural water sources and about 485 acres of man-made water sources are within a 3-mile radius of the accident site.

Immediately west and east, respectively, the North Mouse Creek and the South Mouse Creek enter the Hiwassee River, where it passes under the I-75 bridge. The Hiwassee River meanders west-northwest and enters Lake Chickamauga at a north-northeast and south-southeast series of hills and valleys. The Hiwassee River at Lake Chickamauga is 683 feet above sea level, and the peak elevation of the surrounding hills is 200 to 400 feet above river level.

The four Bowater wastewater storage-treatment ponds (24, 18, 78, and 235 acres, respectively) extend west-northwest of the Hiwassee River. Pond #4 is on both sides of I-75. Bowater's water purification system includes 19 aerators, each capable of spraying 41,000 gallons of water per minute. Seventeen aerators operated during the evening and early morning before the accident. The Bowater plantwide emissions, on a wet-compound, mass-percent basis, are typically 60.65 percent nitrogen, 18.08 percent water vapor, 14.63 percent carbon dioxide, 6.20 percent oxygen, 0.40 percent other, 0.054 percent sulfur dioxide, 0.0029 percent total reduced sulfur, 0.0028 percent particulate, 0.0025 percent nitrogen oxides, 0.0015 percent carbon monoxide, 0.00004 percent volatile organic compounds, 0.000034 percent chlorine dioxide, 0.000003 percent chlorine, and 0.000004 chloroform.

Olin operates three wastewater settling basins, with a combined surface area of about 22 acres, near the South Mouse Creek-Hiwassee River intersection. The Olin stack emissions are typically 75.9 percent nitrogen, 20.2 percent oxygen, 3.9 percent water vapor, 0.0005 percent chlorine, and 0.00001 percent particulates.

The Cleveland wastewater treatment plant operates two settling ponds, one of which has two aerators. The plant processes local sewage and discharges effluent into the Hiwassee River near South Mouse Creek.

Fog Forecasting.--The principal source of public weather information is the NWS, an agency of the National Oceanic and Atmospheric Administration (NOAA). The NWS issues general forecasts for widespread fog affecting a large area when visibility is less than 6 miles. Forecasts can include the potential for localized fog. When dense fog (visibility of 1/4 mile or less) is predicted or observed, advisory forecasts are frequently issued.

In addition, the NWS issues specialized forecasts for user groups, such as aviation, agriculture, forestry, and marine. Many NWS weather forecasts are available through subscription to the NOAA Weather Wire Service. Radio, television, newspaper, and private forecasters use the wire service information to develop weather reports for the public or clients.

Fog Detection.--Certain fog detection instruments can be used to measure visibility. Transmissometers measure visibility based on the intensity of light between a projector and a receptor. Back scatter sensors and forward scatter sensors measure visibility based on the amount of light scattered by the particulates[20] in the atmosphere. These instruments must be in fog to be effective, and their placement is critical in localized fog detection. Two or more instruments may be required to determine the horizontal extent of a fog. Such instruments can monitor a location continuously, and when visibility is reduced to a preselected level, their warning is instantaneous.

The transmissometer projects a focused light beam to a sensor located 250 to 500 feet away. After subtracting ambient light (light from other sources), the instrument measures the intensity of light between the light source and the sensor. Transmissometers are very accurate and have been used at airports for many years. Their disadvantages are that considerable space is required because of their baseline length, that alignment is critical, and that frequent maintenance is necessary.

The back scatter sensor's light source and receptor are positioned and aimed in the same direction. The instrument measures the amount of light scattered back by atmospheric particulates. The back scatter sensor is mounted on a single pedestal and requires little space. One disadvantage is that the reverse light direction transmits a difference in the amount of light scattered by different size particles; for example, in snow, the back scatter sensor measures the visibility lower than it actually is.

The forward scatter sensor measures visibility based on the amount of light scattered at an angle from the beam. Its receptor is a short distance from the light source; a common light path is about 3 feet. The 30- to 40-degree angle between the light source and the receptor provides the most consistent measure of visibility over a wide range of particulate sizes. Forward scatter sensors are mounted on single pedestals and are frequently used at automated airport weather observation stations.

Fog Countermeasures.--The Safety Board reviewed U.S. and European data on limited-visibility countermeasures and in 1991 held a special public hearing on fog. Safety Board investigators also reviewed data contained in surveys requested from

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[20]Fog droplets, blowing dust, smoke, rain, or snow.

the Federal Highway Administration (FHWA)[21] and the International Bridge, Tunnel and Turnpike Association (IBTTA). These data pertained to limited-visibility conditions on limited-access highways.

FHWA Survey--The 1991 FHWA survey comprised 33 questions on fog-related issues. Of the 48 States that responded, 26 reported no fog-related problems, 10 [22] reported only one fog-related high-accident site or suspected site, 3[23] reported two or three such sites, and 9[24] reported at least one site but did not indicate whether they had multiple sites.

For improved highway delineation, five States[25] use RRPMs specifically for guidance through fog, four[26] use wider lane lines or closer spacing between stripes, and two[27] use pavement inset lights to identify the pavement edge. No State reported using highway lighting specifically as a fog countermeasure.

Nine States[28] use changeable message signs (CMSs), sometimes with flashing beacons, to inform drivers of current conditions. States typically post fixed warning signs that read FOG AHEAD or PROBABLE FOG AHEAD; five States indicated that they use CMSs for such messages.

Two States[29] use fixed speed signs to reduce the speed limit during fog. The New Jersey Turnpike Authority (NJTA) uses auxiliary-message overhead CMSs to explain the need for the reduced speed. South Carolina indicated it was considering a proposal to monitor vehicles' speed reductions to determine whether a normal traffic stream exists during fog.

Several States reported that they are investigating the feasibility of using fog detectors; many indicated a reluctance to employ them because of the expense. Fog detection at suspected fog sites requires the placement of numerous detection units for what may be an occasional occurrence. Equipment maintenance and power failures can be problems. In most States, police make the fog observations. Many States use the NWS or private weather forecasting organizations; how, or if, fog is monitored to initiate possible countermeasures could not be determined from the survey results.

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[21]An engineer with the FHWA discussed the survey results in the Safety Board proceedings, a compilation of papers and remarks delivered at the special public hearing on fog-related accidents on limited-access highways.

[22]Connecticut, Virginia, Georgia, North Carolina, South Carolina, Tennessee, Indiana, Iowa, Colorado, and Oregon.

[23]Wisconsin, Texas, and Wyoming.

[24]Massachusetts, New Jersey, Pennsylvania, Kentucky, Montana, North Dakota, Utah, California, and Alaska.

[25]Pennsylvania, North Carolina, Tennessee, Utah, and Alaska.

[26]Pennsylvania, Tennessee, Montana, and California.

[27]Virginia and South Carolina.

[28]New Jersey, Georgia, North Carolina, South Carolina, Texas, Iowa, California, Oregon, and Louisiana.

[29]North Carolina and Alaska.

IBTTA Survey--In 1991, the IBTTA surveyed its 65 active U.S. members concerning fog issues and received 14 responses. Members in California, Michigan, New Jersey, Rhode Island, and Virginia reported a fog problem.

The California Golden Gate Bridge, Highway and Transportation District reported that fog slows traffic. The district uses CMSs that read CAUTION-HEAVY FOG to warn the entering bridge traffic. The signs are activated manually, based on bridge personnel's judgment of traffic conditions and fog density. The district uses RRPMs and high-pressure sodium lighting but not flashing beacons or fog detectors.

The Michigan Grosse Isle Bridge Company reported that it has installed high-pressure sodium lighting as a fog countermeasure and that flashing beacons are activated during adverse weather. It uses neither fog warning signs nor special delineation.

The New Jersey Expressway Authority, which operates the Atlantic City Expressway, found no correlation between fog and traffic accident locations. The authority reported that it uses no fog advisory signs, no special delineation, and no specific overhead lighting in fog-prone areas.

The Rhode Island Turnpike and Bridge Authority (Newport Bridge) responded that it has no high-accident sites. CMSs, which the chief plaza supervisor's office activates to display FOG, REDUCE SPEED, are in place 3/8 to 1/2 mile in advance of the fog area. The authority uses neither flashing beacons nor special delineation; it does use mercury-vapor lighting on the bridge.

The Virginia Chesapeake Bay Bridge-Tunnel District reported that fog occurs several times a year in its jurisdiction. Based on reports of fog from patrol officers, CMSs are manually activated to display CAUTION - FOG AHEAD; flashing beacons supplement the message. Neither special delineation nor specific overhead lighting is used in fog-prone areas.

Safety Board Special Public Hearing on Fog--In April 1991, the Safety Board held a special public hearing concerning fog accidents on limited-access highways to determine how the United States and other countries respond to fog. Sixteen U.S. and European experts discussed countermeasures for fog on highways, driver perception and reaction to fog, and state-of-the-art fog sensing and highway-user system warning devices. (See appendix A.)

During the special public hearing, the NJTA director of operations provided the following chronological overview of turnpike-tested fog countermeasures:

(circa 1950) Four weather master units (20-foot diameter propeller units), installed about 40 feet above ground where fog accumulated, tested (unsuccessful).

(1951) Weather warning signs posted at interchanges.

(1953-58) Neon speed warning signs installed at fog-prone sites.

(1954) Highway fog lights tested (unsatisfactory results).

(1957) Fog horn near Elizabeth and low-level fluorescent lighting near Newark Airport tested (unsuccessful).

(1958) Fog consultant hired to provide expertise on vehicle and road visibility and lighting. Low-level lights, positioned 26 feet above ground at 15-foot intervals for 2,500 feet of road, tested (unsuccessful).

(circa 1960) Toll tickets imprinted with warning to alert motorists to proceed with caution during periods of fog.

(circa 1960) Vehicle convoys attempted during fog (discontinued).

(1962) Some speed limit signs converted to remote control.

(1963) Private weather forecaster hired to provide three daily forecasts and more frequent forecasts when fog or other inclement weather predicted.

(1964) Inset road pavement lights on Pennsylvania extension tested; removed due to maintenance problems. Raised pavement markers not used due to snow plowing problems.

(1967) Trees planted to disburse fog (ineffective).

(1967) Highway fog lights again tested (unsatisfactory results).

(1990) CMSs, together with 135 remote-controlled speed limit signs, installed at 2-mile intervals along length of 118-mile turnpike.

In addition, the NJTA developed a fog manual that, along with the State police manual, outlined notification procedures and action to be taken during fog or other limited-visibility conditions.

NJTA experience, according to the director of operations, indicates that fog cannot be effectively dissipated; consequently, the NJTA has concentrated on early detection of fog and notification of drivers. The authority is also developing a plan for use of CMSs throughout its system. The director of operations said that NJTA priorities include improved fog forecasts, site-specific fog detection, and driver education.

The general manager of the Greater New Orleans Expressway Commission described fog countermeasures for the 24-mile causeway that spans Lake Pontchartrain in Louisiana. The first two-lane span opened in 1956; the second two-lane span, which included seven crossovers, was added in 1969. In 1977, 102 call boxes were installed about 0.5 mile apart to allow motorists to alert causeway police to hazards, and 12 CMSs were installed in 1984. The release of a call box handle activates amber warning lights for 2 miles preceding the hazard, activates the CMSs to warn motorists, and dispatches police to the site. The CMSs enable police to change the speed limit as conditions vary. The general manager concluded that consistent speeds, unless exceptionally high, reduce the possibility of fatalities. RRPMs are in the center and on both sides of the road. The causeway does not have fog detectors.

During fog, causeway police previously used convoys to move traffic. They discontinued this practice and instead escort vehicles single file in the left lane with no passing allowed. The right lane is reserved for disabled vehicles and other problems. Police cars have been equipped with special yellow directional arrows to guide motorists, and specially designed barricades and arrow signs are also used. Causeway personnel monitor the NWS, commercial radio and television, CB radios, and marine traffic for reports of fog and implement the escort when appropriate.

A research scientist with the Virginia Highway and Transportation Research Council described fog countermeasures installed in 1973 on a 5.8- mile section of I-64 on Afton Mountain, Augusta County, Virginia. Three fog-prone areas of the section have fog detectors that determine when to illuminate the 12-inch-diameter light assemblies inset on the edge lines and center of the road. The research scientist reported that the lighting system has led to lower daytime speeds, higher nighttime speeds, increased daytime and nighttime speed differentials, increased nighttime headways,[30] and decreased nighttime platoons.[31] He concluded that these changes in traffic flow characteristics could be construed as producing increased potential for accidents; nonetheless, he believes the inset lighting provides improved delineation, better guidance for drivers, and safer conditions than existed before.

The assistant bridge construction engineer for the South Carolina Department of Highways and Public Transportation reported on the fog countermeasures employed in the construction of the I-526 bridge over the Cooper River near Charleston, which opened in April 1992. The owners of a paper mill located about 2,000 feet from the bridge contended that the environmental impact statement did not sufficiently consider the effects of fog on the bridge. (A 2-mile section of the bridge is within a fog-prone area.) A Federal court ordered South Carolina to develop a plan to reduce the effects of fog on the bridge.

A consulting firm hired by the State determined that fog countermeasures were necessary on the bridge. The countermeasures installed include 6-inch-wide plastic lane and edge lines, diagonal shoulder markings, RRPMs, inset pavement lights, and a fixed, programmed changeable message system that provides message redundancy and driver opportunity to exit before entering the fog-prone area. Closed-circuit television cameras are used for surveillance. Weather conditions and fog are monitored by a meteorological observation station on the bridge and five forward scatter fog detectors. An emergency power generator is available in the event of a power outage. During fog, trucks are segregated in the right lane and their speed is controlled. Bridge closure is the last countermeasure.

A project engineer with the Utah Department of Transportation described countermeasures for recurring radiation fog on I-15 (Beck Street area) in the Salt Lake Valley. High-pressure, sodium-vapor overhead lighting has been installed 40 feet above the road, stream, and hot springs. Flashing beacons have been mounted on the fog warning signs. Snow-plowable, raised RRPMs have been installed on the shoulder and lane lines. Future plans include remote sensors with data processor units, research on ground-dispensed liquefied carbon dioxide to disburse super cold fog, additional RRPMs, and advisory radio broadcasts.

A deputy district director in the California Department of Transportation (CALTRANS) discussed fog countermeasures in the San Joaquin Valley that include weather stations on the I-80 Ridge Route from San Francisco to Reno, toll-free phone

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[30]Distance between vehicles.

[31]Distribution of vehicles traveling one after another.

lines for highway conditions, and emergency news media messages. The NWS issues weather-related road closings in its weather bulletins. Other countermeasures include plans to revamp the convoy system and to install highway advisory radio transmitters, CMSs, RRPMs on lane and left edge lines, and fog stripes on right edge lines.

CALTRANS investigated longitudinal and lateral control of moving vehicles, as well as CMSs, to encourage CB radio users to discuss fog and road conditions. It also considered public education initiatives and development of a pamphlet to inform truckdrivers about fog. In addition, CALTRANS researched collision avoidance radar for individual vehicles, although the devices are not available to the general public.

The chief of the California Highway Patrol (CHP) discussed procedures for reporting widespread fog in the San Joaquin Valley. He stated that CHP officers, including those in three CHP-operated aircraft, routinely report road conditions to the dispatcher, who tapes them for the news media, which in turn publicize the information. A bilingual CHP officer broadcasts traffic and road conditions on commercial radio in the area.

A research engineer for the Dutch Department of Transport described the European experience with detecting fog and controlling traffic during fog. He stated that the forward-scatter fog detector is the preferred unit for highway use. He reported that if visibility in fog is between 328 feet (100 meters) and 656 feet (200 meters), traffic speed is not affected; when visibility is less than 328 feet (100 meters), motorists often follow the vehicle in front of them at an unsafe distance and form a platoon (a group of vehicles traveling near each other). Fog warning signs are not used because drivers who can see the signs can also see the fog. The research engineer added that a message providing distance data is useless because motorists have difficulty estimating distance traveled.

When an accident or poor visibility causes traffic to slow or to stop, serious secondary accidents often occur. To prevent this, the Dutch use an automatic incident detection system that consists of double-loop detectors[32] imbedded in the pavement; output signals from the detectors can sense traffic presence, lane occupancy, speed, and volume. As a vehicle passes over detector, the loop unbalances a tuned circuit, sending an impulse to the detector amplifier. Microprocessors monitor impulses from many detectors and signal overhead CMSs to display consecutively reduced speeds for vehicles approaching the incident. Time elapsed from detection to display is 28 seconds, and the Dutch goal is to reduce this to 8 seconds.[33] A few accidents, but no fog-related injuries or fatalities, have occurred since the system was implemented.

Other fog countermeasures employed by the Dutch include delineators mounted on black posts (more visible in sunlight and fog); high-performance automobiles, which the police use for rapid response to control traffic at accident scenes; airport weather forecasts to predict fog; multilingual radio weather

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[32]A loop detector is wire that is embedded in the road and energized by alternating current; it produces an output circuit closure, which sends a signal to a control unit, when a vehicle passes over it. Double-loop detectors are used to measure vehicle speed and spacing.

[33]The British use a manual system that typically takes 20 minutes to activate a fog warning sign

broadcasts to alert motorists;[34] and fiber optic overhead CMSs to warn about traffic jams, to reduce speed (flashing), and to restrict lanes (slanting light arrow, red cross, and green arrow).

The research engineer noted that the Germans use transmissometers to activate signs that display fog warning messages and maximum speed limits. The French use yellow chevrons that indicate the direction of traffic for each lane. The English use fog detectors and fog warning signs in the London area; during fog warnings, trucks must use the slow lane and cannot pass. The Italians and the Belgians use fog detectors, fog warning signs, and speed control signs.

Other Sources--In early 1992, the FHWA funded the National Research Council's National Cooperative Highway Research Program (NCHRP) Project 20-5, Topic 23-12, "Reduced Visibility on the Highway."[35] The purpose of the project is to inform the States and local agencies about fog and other limited-visibility countermeasures that can be used on problem roads. (See appendix G for summary.)

As a result of the Intermodal Surface Transportation Efficiency Act of 1991, the DOT has authorized $660 million over a 6-year period for an Intelligent Vehicle Highway System (IVHS) program to develop technologies for greater safety on the nation's highways. These technologies involve driver, vehicle, and highway interface and lend themselves to addressing limited-visibility and fog-related problems.

<u>Succeeding Safety Board Investigations</u>--Since this accident, the Safety Board has investigated the following five accidents that involved limited visibility.

About 9:45 a.m. on January 2, 1991, 55 vehicles were in collisions during fog in the northbound lanes of I-215 at the SR 68 overpass near North Salt Lake, Utah. Three people were killed and 19 were injured. No fog warning signs were posted; the posted speed limit was 55 mph. The accident extended about 3/4 mile and closed I-215 about 6 hours. Shortly before this accident, 14 vehicles had been in collisions on the SR 68 overpass. One person was killed and six were injured. Utah Highway Patrol officers detoured the traffic from SR 68 onto I-215, and collisions subsequently occurred in the I-215 northbound lanes.

About 10:25 a.m. on January 9, 1991, 18 vehicles were in collisions during fog on I-5 near Buttonwillow, California. Two people were killed and 10 were injured. No fog warning signs were posted; the posted speed limit was 65 mph. The accident extended about 200 feet and closed the northbound lane about 20 hours and the southbound lane about 11 hours.

About 7:40 a.m. on February 7, 1991, 75 vehicles were in collisions during fog on SR 99 near Fresno, California. Four people were killed and 31 were injured. No fog warning signs were posted; the posted speed limit was 65 mph. The accident extended about 6 miles and closed SR 99 about 9 hours.

Between 1 and 2:40 p.m. on November 29, 1991, 164 vehicles were in collisions during blowing dust on I-5 near Coalinga, California. Seventeen people were killed

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[34]Commercial transport of hazardous materials is forbidden during a fog-alert broadcast.

[35]The Transportation Research Board (TRB) will distribute the study to its members and State transportation officials.

and 151 were injured. No blowing dust warning signs were posted; the posted speed limit was 65 mph. The accident extended about 2 miles and closed I-5 about 29 hours.

Between 10:40 and 11:05 a.m. on April 20, 1992, 53 vehicles were in collisions during fog on I-64 on Afton Mountain, Virginia. Two people were killed and 25 were injured. Fog warning signs were posted; inset light assemblies were installed that activated automatically when fog was present; the posted speed limit was 65 mph. The accident extended about 1,600 feet and closed the westbound lane about 6 hours and the eastbound lane about 4 hours.

Fog-related Accident Data/Calhoun, Tennessee.--The 1974-88 accident data show the number of accidents that occurred from MP 32 to MP 38, which includes the December 1990 accident site, ranged from 10 (1982) to 32 (1978 and 1988). (See appendix H.) Between March 1974 and April 1979, six multiple-vehicle accidents resulted in 6 fatalities, 65 injuries, and 117 damaged vehicles. The accident rate[36] of the I-75 accident section ranged from equal to triple the accident rate of the Tennessee interstate system; it was double in 1988.

After a multiple-vehicle fog-related accident on November 5, 1978, the Tennessee Office of Urban and Federal Affairs, Highway Safety Planning Division, asked the University of Tennessee Transportation Center to investigate the probable causes of fog near I-75 and Calhoun. The center studied topographic maps and aerial photography of the area to determine the extent and sources of fog and listed as potential sources: the Hiwassee River, the Bowater and Olin facilities, and the salt storage facility on the Hiwassee River between Bowater and I-75. The researchers noted that "to determine conclusively the causes of fog formation, a more detailed study would be required. The area has high potential for early morning inversion, as do many other areas in the Tennessee Valley." They further stated:

> The brief review of the problem and the study area have not revealed any obvious solutions to the problem. Under the relatively wide range of meteorological conditions which might exist, conditions favorable to fog formation can develop in less than one hour. An advance warning system based on meteorological conditions is probably not a good solution to the problem due to the very low mixing heights which exist in the early morning and due to the well-defined valleys created by ridges.

After the multiple-vehicle fog-related accident on April 15, 1979, the standing TDOT highway safety diagnostic team[37] prepared a study for the Tennessee Commissioner of Transportation. Submitted on April 30, 1979, the study stated, "The obvious solution to this problem is to eliminate the fog and the Department's Research and Planning Division is conducting a study into this area." The diagnostic team recommended improving edge and center striping, installing raised pavement markers, providing portable detour signs to the THP, monitoring traffic and weather conditions frequently, detouring traffic, increasing fog warning signs, adding

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[36]Accidents per one million miles traveled.

[37]Seven TDOT employees and one THP representative.

flashing lights to existing warning signs, and preparing written procedures for traffic control warnings on fog, accidents, and detours.

The recommended safety improvements were completed by May 1980. The TDOT installed thermoplastic edgeline and lane line pavement markings, RRPMs at 20-foot centers on the centerline, RRPMs at 40-foot intervals on the edgelines, delineators at 90-foot intervals on the outside shoulder, diagonal thermoplastic markings with five RRPMs at 45-foot centers on the outside shoulder, an additional 6- by 12-foot advance fog warning sign on the left shoulder opposite the existing fog warning signs, and two manually activated flashing beacons on all four fog warning signs.

From May 1980 until December 10, 1990, no multiple-vehicle fog-related accidents resulting in fatalities or injuries occurred on that section of I-75.

As a result of its investigation of a series of multiple-vehicle collisions on I-75 near Charleston, Tennessee, on November 5, 1978,[38] the Safety Board issued three safety recommendations to the Commissioner, Tennessee State Department of Safety on June 7, 1979:

H-79-33

Develop and implement a standing adverse weather and road condition plan that will include:

1. A procedure for alerting public safety officials and the driving public of fog conditions through hazardous driving advisories on radio and television.

2. A procedure for the strategic and timely deployment of patrol units to affected areas.

3. Criteria for the rapid closing of affected sections of highway and the rerouting of traffic.

4. Mutual assistance compacts with local government entities for emergency aid.

5. Methods for the safe evacuation of vehicles trapped on affected sections of the highway.

H-79-34

Determine the feasibility of installing an available fog detection and warning system at the Interstate 75 crossing of the Hiwassee River near Charleston, Tennessee.

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[38]Field investigations ATL-79-F-H006 and ATL-79-F-H023, respectively.

H-79-35

Until such time as an automatic fog detection and warning device is installed, provide more frequent patrols on the affected section of Interstate 75 when fog is forecast so that the earliest practical warning may be available.

The Tennessee Department of Safety responded to these safety recommendations on June 14, 1979, stating: "Our interdepartmental effort involving Safety, Transportation and Highway Safety is underway to correct the problem addressed by your recommendation."

In letters dated February 6, 1981, May 5, 1983, and September 27, 1983, the Safety Board requested more specific information about the actions taken by the Tennessee Department of Safety. The department replied in a letter dated August 16, 1983, that listed the following measures implemented by the THP:

1. If the situation occurs in the Calhoun fog area, the affected Public Safety officials are notified by the Tennessee Highway Patrol dispatcher by radio or telephone. Local radio stations are advised of the situation. They, in turn, make spot announcements.

2. The Tennessee Highway Patrol has a trooper on patrol in the Calhoun area at all times. In addition, a trooper is posted in the fog area from 5:00 a.m. until 9:00 a.m. (This time frame was established by researching the accident files, etc.) Bowater Southern Paper Security periodically patrols the fog area and if the need arises, the Tennessee Highway Patrol office is notified and appropriate action is taken.

3. All necessary signs and postings have been erected for detouring traffic around the fog area. If it becomes necessary to detour traffic, two (2) officers can complete the detail.

4. Two (2) meetings have been held with all local and state officials to complete a mutual assistance pact. Until this agreement is reached, all concerned have agreed to respond to any emergency situation.

5. All towing services in the immediate area are familiar with the existing problem and will respond to any emergency at any given time.

In addition to the above mentioned measures, delineators have been set in the pavement at very close intervals. Flashing warning lights are in effect in the north and south bound lanes of I-75 prior to entering the area. These lights are activated by the first officer on the scene when the need arises.

Since these measures have been in effect, the Tennessee Highway Patrol has not had to respond to any major accidents in the fog area.

Based on the actions described by the Tennessee Department of Safety, the Safety Board classified Safety Recommendations H-79-33 and H-79-35 as "Closed--Acceptable Action" on October 31, 1983. Because the department stated that the THP had not had to respond to any major accidents in the Calhoun fog area since the corrective measures had been implemented, Safety Recommendation H-79-34 was classified as "Closed--No Longer Applicable."

Safety Board investigators on scene at the December 11, 1990, accident noted that reflective pavement markers were in place on I-75 and that advance dense fog warning signs were posted and visible.

Tennessee Procedures for Fog on Highways.--The THP had about 45 troopers available for duty in 11 counties. Because of the troopers' routine scheduling, special assignments, training commitments, and leave requirements only one trooper could be on duty per county.

The THP captain stated that before the December 1990 accident, verbal directives had been given to troopers about the operation of flashing beacons (flashing beacons were to be activated when fog became visible); no written policies or procedures had been issued. If troopers determined that conditions warranted it, traffic was to be slowed by parking a patrol car with blue lights flashing in advance of the fog area. If troopers observed the fog worsening, the dispatcher was to be notified, and the supervisor was to be contacted for further instructions.

The TDOT and the THP could also reroute traffic from I-75 when dense fog was observed. The THP captain stated that since he had been assigned as Chattanooga district captain in 1980, I-75 between MPs 32 and 38 had never been closed because of fog until the December 1990 accident.

On April 22, 1991, the THP issued a formal I-75 Fog Zone Contingency Plan for use between MPs 29 and 39 in Bradley and McMinn Counties. According to the plan: (a) A trooper will be assigned to the fog-prone area from 5 to 10 a.m. daily. (b) Trooper(s) will patrol the fog-prone area at the beginning and end of and periodically during the midnight shift. (c) Trooper(s) will patrol the entire fog-prone area immediately after beginning the first shift. (d) If fog appears, a trooper will activate the flashing beacons for the northbound and southbound lanes and notify the dispatcher, who will contact the local sheriff's departments and news media. (e) When fog dissipates, a trooper will deactivate the flashing beacons and notify the dispatcher, who will contact the local sheriff's departments and news media. (f) While the beacons are flashing, a trooper will patrol and monitor the fog-prone area and, if necessary, will park his patrol car with lights flashing in advance of the fog to slow traffic; the trooper will request another trooper to do the same procedure in the opposite lanes. The dispatcher will notify the supervisor and then follow the notification procedures in (d). (g) If the fog is dense, traffic will be rerouted to U.S. Route 11, unless all routes are impassable, in which case traffic will be stopped, and the routine notification procedures will apply. (h) The THP Chattanooga district captain will be responsible for executing the contingency plan.

The TDOT is responsible for identifying and dealing with hazardous areas, including fog sites on the interstate highway system. The department identifies high accident frequency by computing highway accident rates based on THP traffic accident reports. Computations are based on the number of accidents per million vehicle miles traveled for specific highway section lengths. Higher than normal accident patterns are compared with road curvature, traffic volume, and vehicle speeds. After conducting engineering analyses of traffic, accident, and environmental data, the TDOT develops countermeasures, which it evaluates by comparing accident ratios before and after implementation.

Subsequent to the April 1991 THP Fog Zone Contingency Plan, the TDOT and the THP prepared a three-phase Plan of Action and a Surveillance and Response Plan for the fog area on I-75 from MP 25 to MP 44 in Bradley and McMinn Counties. (The THP I-75 Fog Zone Contingency Plan is to be revised to support the TDOT and THP Plan of Action.) On July 14, 1992, the concept for phases II and III of the plan was approved; phase I was completed on October 15, 1991, with the following improvements: the surface was overlaid; snowplowable RRPMs were installed at 20-foot intervals along the I-75 and detour route centerlines; surface-mounted RRPMs were installed at 40-foot intervals along the edge lines; RRPMs were replaced on the outside shoulder diagonal lines; 6-inch-wide thermoplastic edgelines were installed on the inside and outside shoulders; lane line patterns were installed using 6-inch-wide thermoplastic lines with 10-foot spacing; reflectors on brown posts were placed on 80-foot centers along the outside shoulder; and two LIGHTS ON IN FOG message signs were installed.

Phase II entails installation of programmed overhead CMSs for passable fog with a 50-mph speed limit (six or more delineators yield more than 480 feet of visibility), passable fog with a 35-mph speed limit (three to six delineators yield 241 to 480 feet of visibility),[39] and road closure-detour (one to three delineators yield less than 240 feet of visibility); changeable speed limit signs; warning signs with flashing beacons and automatic barrier gates; highway advisory radios and a CB transmitter; and two weather stations and two forward scatter fog sensing devices to record and transmit temperature, humidity, wind speed, and visibility levels to the THP's central dispatch office. In addition, the THP and local agencies are to develop a Surveillance and Response Plan. Under phase III, adjustments based on findings and experience are to be made to the overall plan.

The plan calls for the TDOT to maintain the weather and traffic control devices. The THP is to provide a trooper to monitor the fog-prone section from predawn to midmorning, and surveillance is also to be provided on each routine THP patrol during the day. A trooper is to be dispatched to the fog-prone area when the automated weather observations system alerts the dispatcher that the atmospheric conditions favor development of fog. Either the on-scene trooper or the dispatcher can activate the system; authorize road closure; activate or deactivate the CMSs, flashing beacons, changeable speed limit signs, ramp gates, and highway and CB advisory radios; and mobilize additional resources from the THP and local agencies. The TDOT and the THP are to form a system management committee, which will meet at least twice a year to evaluate the plan.

Driver Training Manuals.--The American Association of Motor Vehicle Administrators[40] (AAMVA) issues model State driver licensing manuals (SDLMs), commercial driver licensing manuals (CDLMs), and accompanying tests. Using these models, State driver licensing authorities prepare SDLMs, CDLMs, and tests. Initial license applicants, license renewal applicants, and suspended or revoked license

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[39]Delineators on the outside shoulder edge provide specific guidance in determining a safe speed in relation to the fog density.

[40]A national association of directors of State driver licensing agencies

applicants use the manuals to study for the driver license test. During the Safety Board investigations of fog-related accidents in Tennessee, California, and Utah, investigators examined these States' driver license handbooks.

In the section "HOW TO AVOID REAR-END COLLISIONS," the *Tennessee Driver Handbook and Driver License Study Guide* advises:

> Adjust Your Driving to Conditions - When driving conditions are less than ideal all persons operating motor vehicles on the public highways shall drive at a careful and prudent speed not greater than is reasonable and proper having due regard for the following conditions:
>
> -TRAFFIC- When traffic is heavy, congested or moving slowly.
>
> -SURFACE- When the road surface is rough, icy, wet or otherwise provides poor traction.
>
> -WIDTH- When the width of the roadway reduces your margin of safety.
>
> -WEATHER- When weather conditions affect sight distance and traction (rain, snow, fog, dust, or smoke).

The *California Driver Handbook* states in its "Hazardous Conditions" section:

> FOG . . . . The best advice for driving in fog is "Don't." If you must drive, greatly reduce your driving speed. Turn on your headlights. You will be able to see further if you use low beams. Be prepared for emergency stops. If the fog becomes so thick that you can barely see, pull completely off the roadway and stop until visibility improves.

The "Stormy Weather" section of California's handbook advises, "Rain and fog demand that you slow down. It is wise to turn on your headlights when visibility is poor -- even in daylight." The "Night Driving" section adds, "It is best to turn your headlights on at sunset and whenever it is raining or foggy."

The *Utah Driver Handbook* does not refer to fog, nor do the Tennessee handbook, the *California Commercial Driver License Manual*, and the *Utah Commercial Vehicle Driver's Manual*.[41] (See appendix I for a discussion of previous Safety Board recommendations concerning driver instruction and education for limited-visibility situations.)

Driver Behavior Studies.--The Safety Board has reviewed several studies and articles pertaining to driver behavior in limited-visibility situations.

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[41] The Commercial Motor Vehicle Act of 1986 requires that States adopt uniform minimum licensing and testing standards for commercial vehicle drivers.

In a California study,[42] researchers evaluated driver behavior in several fog-prone areas and the effects of countermeasures on speed and headway. They found that (a) mean speed reduction during fog was 5 to 8 mph (only slight speed reductions were noted during high-volume daytime and low-volume nighttime); (b) speed variability did not decline during fog; (c) speed variability on expressways declined when speeds were posted; (d) posted speeds less than 35 mph had little effect on speed reduction; (e) drivers drove at higher speeds than those posted or appropriate for sight distance; (f) neither fog nor posted speeds affected headways; (g) radio information was ineffective in reducing speed variability in daytime and nighttime fog but led to significant speed reductions during light nighttime fog; and (h) taillights were ineffective. The researchers also concluded that CMSs should only be used where severe fog problems exist because of the high cost of installation and their limited effectiveness.

Data from a Virginia study[43] on the use of inset pavement lights in fog showed that (a) the lights led to decreased daytime speeds and increased nighttime speeds, (b) speed variability increased after inset pavement light installation, (c) drivers operated at unsafe stopping distance speeds under any lighting or visibility condition, and (d) drivers relied on the inset pavement lights rather than the vehicle in front for guidance.

Oregon researchers who studied[44] the use of speed advisories during limited visibility found that (a) posted speed and visibility conditions affected speed variability, (b) signing schemes based on stepped-down speeds produced gradual deceleration with uniform speed when entering fog, (c) drivers lost confidence in a system after more than two false information messages, and (d) drivers in fog preferred to follow another vehicle (46 percent), to follow pavement stripes (29 percent), or to pull off and stop (5 percent).

ANALYSIS

Introduction

General.--While investigating the Calhoun accident, the Safety Board examined witness statements, police accident reports, photographs, videotapes, and vehicle damage (when practical). Based on this information, the mechanical condition of the vehicles involved in the initial collisions and the physical condition of the road were eliminated as casual factors. The hazardous materials involved did not contribute to the severity of the accident. Moreover, sufficient emergency medical personnel and firefighters were dispatched and deployed at the accident scene; McMinn County, Bradley County, and the TEMA effectively coordinated on-scene fire and emergency medical resources. The Safety Board determined that the effectiveness of emergency medical services prevented further loss of life and aggravation of injuries.

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[42] T. N. Tamburri and D. J. Theobald, *Reduced Visibility (Fog) Study*, California Division of Highways, Traffic Department, (Report HPR-4, March 1967).

[43] F. D. Shepard, *Traffic Flow Evaluation of Pavement Inset Lights for Use During Fog*, Virginia Highways and Transportation Research Council, (Report VHTRC 78-R25, December 1977)

[44] D. R. Wagner and D. K. Hofstetter, *Speed Advisory Information for Reduced Visibility Conditions*, Oregon State Department of Transportation, Federal Highway Administration, Report FHWA-RD-78-32, March 1978).

During rescue and salvage operations, vehicles were removed before being examined or measured; therefore, the Safety Board could not collect sufficient data for complete accident reconstruction.

Limited-Visibility Accidents.--In the Calhoun accident, Safety Board investigators found the following significant factors: multiple-vehicle rear-end collisions involved slowed or stopped vehicles; drivers operated their vehicles at various speeds following the sudden loss of visibility; collisions occurred on a highway periodically subject to limited visibility; troopers routinely patrolling I-75 were used to detect limited-visibility conditions; no traffic flow detectors or automatic visibility sensors were used; no fog countermeasures or traffic control procedures were initiated before the collisions (however, the southbound beacons had been activated 3 days before the accident); and no drivers had been provided with specific behavioral guidance[45] or instructions on responding to limited-visibility situations.

Investigators found that several of these factors were also present in the other limited-visibility accidents recently investigated by the Safety Board. In this report, these factors have been grouped into three areas for analysis: nonuniform driver behavior during limited-visibility conditions, detection of limited-visibility conditions, and limited-visibility countermeasures.

Nonuniform Driver Behavior during Limited Visibility

The Calhoun Accident.--Most drivers stated that they encountered light fog and saw the fog warning signs before entering the dense fog near the SR 163 overpass. Many drivers apparently did not recognize or were not convinced that dense fog might lie ahead. The Safety Board believes that the presence of light fog and the fog warning signs were distinct clues that dense fog and hazardous driving conditions might be ahead. Some drivers slowed their vehicles for the light fog, some slowed for the dense fog, and others slowed only when they encountered vehicles that had slowed or stopped. Some drivers never slowed and consequently collided with other vehicles that did slow or stop. Therefore, the Safety Board concludes that in the multiple-vehicle collisions near Calhoun, drivers responded to the sudden loss of visibility with varying reductions in speed.

Other Accidents and Information.--The same nonuniform driver response (varying reductions in speed) to sudden limited-visibility situations occurred in the other limited-visibility accidents recently investigated by the Safety Board. In the absence of specific behavioral guidance, drivers perceived risks differently in sudden limited-visibility conditions. Based on its investigations and research, the Safety Board determined that accidents during limited visibility are primarily due to varying vehicle speeds in the traffic stream. The Safety Board believes that to prevent multiple-vehicle collisions during such conditions, countermeasures are needed that ensure drivers proceed through limited-visibility conditions at uniform reduced speeds.

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[45] Specific behavioral guidance, as used in this report, is any information provided to motorists that conveys precisely the behavior desired.

Detection of Limited-Visibility Situations

The Calhoun Accident.--Fog formation can occur suddenly, can be very localized, and can be difficult to detect unless a fog-prone area is continuously monitored. THP troopers patrolling I-75 near Calhoun were neither provided with specific guidance on what constitutes a hazardous limited-visibility condition nor specifically assigned there to patrol for fog; nonetheless, they were to report fog if it became a hazard. About an hour before the accident, troopers observed light fog near the SR 163 overpass but did not consider it hazardous. After they left the area, the fog became dense, but the troopers did not detect the change because the routine THP patrols did not continuously monitor the fog-prone area. The THP apparently discontinued the intensive patrols that had been instituted as a result of the Safety Board's earlier safety recommendations.

The THP I-75 Fog Zone Contingency Plan implemented after the accident calls for a trooper to be assigned to the fog-prone area between 5 and 10 a.m. daily. This trooper is not usually reassigned for routine incidents but can be dispatched if needed, at which time the fog patrol ceases unless a replacement trooper is assigned. Although a trooper patrols for fog from 5 to 10 a.m., fog can form at other times and may not be detected. Because dense fog can form suddenly anywhere within the fog-prone area, a patrolling trooper may not be present where and when fog occurs. Even when a trooper detects fog, the plan does not provide specific guidelines for determining whether the highway is hazardous. Nor does it provide for obtaining weather conditions from nearby industrial facilities. Therefore, the Safety Board concludes that the THP I-75 Fog Zone Contingency Plan does not ensure the prompt detection of fog or changes in its density.

The 1992 TDOT and THP Plan of Action and the Surveillance and Response Plan are improvements over previous plans for detecting limited-visibility conditions in the fog-prone area of I-75 near Calhoun. Phase I of the Plan of Action focuses on countermeasures for improving motorists' ability to see the road during limited-visibility conditions. Such countermeasures apparently functioned successfully during the accident, and the Safety Board believes that TDOT's use of state-of-the-art road marking to prevent drivers from unintentionally leaving the road during limited-visibility conditions is warranted. The Safety Board believes that the TDOT effort to improve road markings will help ensure that motorists do not unintentionally leave the road during limited-visibility conditions (fog) on I-75 near Calhoun.

Phase II of the plan features CMSs, highway advisory radios, and warning signs with flashing beacons to alert drivers to limited-visibility conditions, speed limits, and road closures or detours; however, it lacks sufficient specific behavioral guidance for motorists. In addition, phase II and the Surveillance and Response Plan rely heavily on the THP trooper on scene as an observer, two weather stations, and two forward scatter visibility detectors. The Safety Board is concerned that these proposed countermeasures will not ensure the prompt detection of fog for several reasons: the patrolling trooper may not be in the area when fog forms or becomes hazardous; the weather stations and visibility detectors are too few to cover the entire fog-prone area; and, most important, the countermeasures do not include the detection of traffic flow disruption.[46]

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[46]Interruption of the free flow of traffic

A significant difference between limited-visibility accidents and other highway accidents is the greater frequency of secondary multiple-vehicle collisions during the former. When drivers perceive a hazardous road condition, many, but not all, slow their vehicles. As in the Calhoun accident, secondary collisions often occur when relatively high-speed traffic encounters slowed or stopped vehicles. Detection of such traffic flow disruption is therefore critical and can be accomplished by devices, such as loop detectors and radar, that monitor traffic flow. When a disruption occurs, traffic following the slowed vehicles must be immediately and uniformly slowed to avoid speed variation and secondary collisions throughout the hazardous area. Detection of the hazardous condition, such as fog, will not by itself ensure rapid, uniform speed reduction or prevent speed variation. The Safety Board concludes that a comprehensive limited-visibility countermeasure system should include both traffic flow detectors[47] and visibility sensors that automatically activate traffic control devices when either hazardous conditions occur or traffic slows. The 1992 TDOT and THP Plan of Action and the Surveillance and Response Plan, which did not include traffic flow disruption as a component, may not ensure the timely detection of hazardous limited-visibility conditions.

Other Accidents and Information.--In the other recent accidents investigated by the Safety Board, police patrols were also used to detect limited-visibility conditions. However, they were not able to detect the fog or dust in time to implement countermeasures that might have prevented or reduced the severity of the accidents. Police patrols are resource intensive and make subjective observations. The Calhoun[48] and other accidents clearly demonstrate the inconsistency in and inadequacy of this practice. Recent advancements in traffic flow disruption and limited-visibility detection equipment provide alternatives to police patrols. Therefore, the Safety Board concludes that reliance on police patrols to detect limited-visibility conditions will not ensure their timely detection.

According to the NWS, meteorologists can often accurately forecast the onset of conditions necessary for fog formation. However, even when those conditions are ideal, fog does not always develop; conversely, it may develop when conditions are less than ideal. When possible, the NWS predicts the potential for area-wide fog, but it is neither tasked nor manned to forecast weather for small localities, such as the Hiwassee River Valley near Calhoun. Therefore, the Safety Board concludes that although weather forecasts may alert authorities to the possibility of fog formation, they are not sufficiently accurate, comprehensive, or timely to predict that fog will form in a specific area.

During the Safety Board special fog hearing, several speakers discussed fog detection and the significant improvements in visibility sensor technology during the last 10 years. When strategically placed on a highway, sensors can accurately detect fog, as well as snow, rain, smoke, and dust. Such devices are being used successfully at airports, which occupy a comparatively small geographical area; however, highways that are subject to limited visibility may extend over several miles. Therefore, if visibility sensors are to be effective in highway applications, they must

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[47]Traffic flow detectors are considerably less expensive than visibility sensors and can be installed throughout the fog-prone section of highway.

[48]About 45 troopers were available for road duty for 11 counties. Frequently, only one trooper was on duty in each county.

be strategically placed throughout a limited-visibility-prone area as one component in a comprehensive fog countermeasure system.

Limited-Visibility Countermeasures

The Calhoun Accident.--By 1979, the TDOT had identified the I-75 fog-prone area near Calhoun and by early 1980, had implemented the countermeasures recommended by the Tennessee diagnostic study team. Those countermeasures included improving edge and center line striping and installing RRPMs. Although visibility was poor on I-75 during the 1990 accident, investigators found that no driver apparently left the road unintentionally.

The diagnostic study team also recommended increasing the number of fog warning signs and adding flashing beacons to existing warning signs. At the time of this accident, the warning signs and flashing beacons advised drivers that fog was present; however, some drivers stated that even so, they did not slow their vehicles before conditions worsened. Some drivers familiar with the highway doubted the credibility of the southbound fog warning sign because its beacons had been flashing for the previous 3 days during clear weather. Since the accident, the TDOT has installed LIGHTS ON IN FOG signs; nonetheless, this advisory is not likely to prevent speed variation because drivers may respond differently to the information. The LIGHTS ON IN FOG sign is an example of nonspecific behavioral guidance (preferred specific behavioral guidance, mentioned in numerous driver licensing manuals, would be USE LOW BEAM to improve sight distance). The Safety Board concludes that the fog warning signs and flashing beacons were not sufficient to produce uniform driver behavior and were ineffective in part as warning devices in this accident because they did not consistently reflect actual conditions.

Respondents to the Safety Board questionnaire for the Calhoun accident often noted the discrepancy between activated fog warning beacons and the lack of fog that led many drivers to ignore the signs in the fog-prone area. Similar behavior has been reported in earlier studies of fog-prone areas[49] and construction zones[50] and in the Safety Board special fog hearing.[51] The Safety Board believes that the credibility of highway and weather condition warning and behavioral guidance signs is essential to reducing speed variation. Therefore, these signs should be activated only during limited-visibility conditions and should be promptly deactivated when the message is no longer appropriate. During limited-visibility conditions, when strict traffic control is effected through CMSs, one noncomplying driver can cause variations in speed that severely disrupt traffic flow and lead to collisions. Therefore, drivers need to be informed about the importance of obeying these signs, and compliance should be strictly enforced.

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[49]Richard N. Schwab, "Minimizing the Hazard of Restricted Visibility in Fog," *Public Roads*, September 1972, p. 56.

[50]At the January 1991 Transportation Research Board Human Factors Workshop on Construction Zones, attendees agreed that inappropriate signing in construction zones has led to a national disregard of many highway signs. Motorists reported that they delay altering their speed or exercising caution until in sight of the hazard or construction ahead.

[51]Several speakers stated that after just one experience with an inappropriately messaged sign, a driver may need 20 or more subsequent exposures to a correctly messaged sign to again have confidence in its message.

At the time of the accident, other fog countermeasures for I-75 near Calhoun included parking a THP car with emergency lights flashing ahead of the fog area to slow and redirect traffic onto alternate routes and closing the affected section of the highway. Although troopers detected fog in the area, they did not consider it hazardous; consequently, no THP countermeasures were initiated.

Since the accident, the THP has implemented a formal, written plan that is similar to previous practice. The plan includes parking a patrol car with emergency lights flashing in advance of the fog area to slow traffic. Although this countermeasure may temporarily slow traffic, it will neither provide drivers with specific behavioral guidance, such as SLOW TO AND MAINTAIN 25 MPH, nor ensure that drivers operate their vehicles at uniform reduced speeds through the affected area. Therefore, the Safety Board concludes that the new THP plan does not provide sufficiently specific behavioral guidance for motorists on uniform speed during limited visibility to be an effective countermeasure and to prevent multiple-vehicle collisions.

The new THP plan also includes highway closure and traffic detour, which require considerable time and resources for successful implementation. The THP had not closed I-75 near Calhoun for fog-related reasons in the 11 years preceding the accident; consequently, the effectiveness of this countermeasure could not be evaluated.

The Safety Board believes that the TDOT, in cooperation with the THP, should revise the plan of action and the surveillance and response plan. The plans should provide for the immediate detection of traffic flow disruption and fog, uniform driver response to reduce and maintain traffic speed in advance of and through the hazardous area, enforcement of countermeasures, and a public information and education program to ensure that motorists receive specific behavioral guidance for the fog-prone area. The strategic placement of traffic flow detectors that automatically activate traffic control devices would ensure prompt detection of hazardous conditions other than fog, such as an accident, and would alert drivers to make appropriate speed reductions in advance of and through the area.

<u>Other Accidents and Information</u>.--In the United States, highway signs typically inform motorists of hazardous weather conditions (FOG AHEAD) and give advisories (SLOW or BE ALERT). General on-site behavioral guidance is not sufficient to achieve uniform speed reduction. In the Calhoun accident, the posted fog area signs failed to persuade many drivers to reduce their speed, even in the presence of fog. In the Coalinga and Afton Mountain accidents, signs instructing drivers to slow were posted on the roads; however, the signs did not advise the specific speed that drivers should slow to, and as a result, speed variation developed. Also, before the Coalinga accident, condition warnings had been broadcast over the radio, but the collisions still occurred. Because radios may be off or not tuned to a station broadcasting the warnings, weather condition radio broadcasts may not reach all motorists on the highway.

European transportation officials, particularly the Dutch, have achieved uniform driver behavior and a reduction in speed variation through limited-visibility areas by implementing comprehensive countermeasure plans that include detection, automated traffic control, and enforcement. CMSs display appropriate speeds and provide specific behavioral guidance for drivers; double loop detectors and microprocessors sense the traffic flow and detect disruptions; speed limits in advance of and through the strictly controlled section of road are automatically adjusted and uniformly maintained; and police aggressively enforce the posted speed limits. Thus, drivers traveling about the same speed uniformly enter and safely proceed through the hazardous area. Such strict traffic control is not common on U.S. highways and requires carefully designed highway engineering practices, enforcement, and public education programs to make it a viable countermeasure.

According to the testimony at the Safety Board special fog hearing, only a fraction of U.S. highways have limited-visibility-prone areas that require strict traffic control. Nevertheless, drivers should be familiar with traffic control devices on roads subject to limited visibility and strict traffic control. From the investigation of other limited-visibility accidents and the special fog hearing testimony, the Safety Board has learned that many States have implemented countermeasures for recurring limited-visibility conditions. Those countermeasures vary, and the disparity among States could cause driver confusion and result in nonuniform driver response. Since preventing limited-visibility accidents involving multiple-vehicle collisions requires uniform driver response, countermeasures should be similar nationwide to minimize driver confusion.

In reviewing driver license manuals from States in which it had recently investigated limited-visibility-related accidents, the Safety Board discovered inconsistencies in guidance for driving in fog and other limited-visibility conditions. The Safety Board believes that uniform specific guidance for driving during fog and limited-visibility conditions should be developed and incorporated in driver license manuals and tests. The Safety Board also believes that the NHTSA, the FHWA, the AAMVA, the American Automobile Association, and the American Driver and Traffic Safety Education Association should cooperate in reviewing and updating driver license, educational, and remedial training materials to ensure that guidance for driving during limited-visibility conditions is uniform and complete; that the NHTSA and the AAMVA should develop model test questions for licensing examinations on driving during limited-visibility conditions; and that the AAMVA should develop inserts concerning countermeasures that motorists should consider when driving during fog and other limited-visibility conditions and advise its members to enclose such inserts with driver license renewals, motor vehicle registration renewals, and similar mailings.

In 1979, the FHWA issued the *User Guidelines for Reduced Visibility Guidance System Design* to help transportation officials "estimate the need for a reduced visibility guidance (RVG) system, configure candidate systems, and make cost-utility comparisons to choose a system." The guidelines provide performance comparisons of devices used in the systems but do not discuss recent technological advances.

Although the FHWA has funded NCHRP Project 20-5, Topic 23-12, the FHWA has not designated fog or other limited-visibility conditions for priority consideration in its Research and Technology (R&T) Program. That program is a 5-year plan updated annually to address critical national highway transportation needs; it typically results in considerable benefit to State and local transportation officials. While catastrophic limited-visibility accidents are relatively infrequent, the potential for loss of life and property damage exists when they do occur. The NCHRP project will provide State highway officials with valuable information about limited-visibility countermeasures but will not necessarily influence the States to develop comprehensive limited-visibility countermeasure programs. The Safety Board concludes that if the FHWA were to promote the latest developments in fog and other limited-visibility countermeasures through the R&T Program, the States would participate and the number and severity of limited-visibility accidents could be reduced. Therefore, the Safety Board believes that following the completion of NCHRP Project 20-5, Topic 23-12, the FHWA should ensure the continued development of effective fog and other limited-visibility countermeasures and make information about them available to States on a timely basis.

In addition, the Safety Board believes that the IVHS program offers a unique opportunity to develop and implement limited-visibility traffic control countermeasures. Traffic flow detectors, automatic message and vehicle speed control systems, and radar vehicle detection to warn of preceding objects, such as other vehicles, are all appropriate candidates for IVHS projects. The Safety Board believes that the DOT should include limited-visibility countermeasures in demonstration projects funded through the IVHS program.

Fog Formation Near Calhoun

During the night of December 10 and the morning of December 11, conditions conducive to fog formation existed in the Calhoun area. On the morning of the accident, radiation fog developed in the vicinity of Calhoun, and steam fog and radiation fog developed over North Mouse Creek and other bodies of water near I-75 and the SR 163 overpass. Moreover, the Bowater stack emissions contained highly hygroscopic sulfur compounds (effective nuclei for fog formation), and the aerators and storage ponds introduced water vapor into the air. In the morning hours, light surface winds recorded by Bowater's anemometers indicated a possible convergence of air into the industrial operations area.

Before the accident, fog formed, severely limiting visibility, and its density or movement could have changed under one or all of the following scenarios: (1) Radiation fog or steam fog may have suddenly increased in density. (2) Steam fog may have combined with radiation fog and drifted across I -75 because of ambient winds, the topography,[52] or a thermal updraft.[53] (3) Emissions from Bowater's stacks may have increased fog density near the Bowater facility and the accident site. (4) Fog that formed near the Bowater facility may have drifted across I-75. Although Bowater's anemometers indicated wind convergence, those readings may not have been representative of conditions at the accident site due to the distance of the instruments from the accident site, the characteristics of the terrain, or micrometeorological[54] conditions. The Safety Board concludes that any one of a combination of meteorological and industrial effects may have influenced the formation, density, and subsequent movement of the fog on the day of the accident.

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[52]Cool air drainage occurs over sloping terrain primarily at night and during the early morning hours when no overriding surface winds are present. The surface cools by radiation and, in turn, cools the adjacent air by conduction. The cooler, denser air follows the natural features of the terrain, seeking the lowest spot.

[53]A rising air current, similar to a chimney draft, that occurs only when no overriding ambient winds are present. Aerial photographs of the fog shortly after the accident showed a plume over the Bowater plant indicating a thermal updraft.

[54]Micrometeorology deals with the observation and explanation of the smallest scale physical and dynamic occurrences in the atmosphere.

Puncture of Dicumyl Peroxide Tanks

Postaccident examination of the tractor-semitrailer involved in the first southbound collision and subsequent fire revealed that 3 of its 10 portable dicumyl peroxide tanks were punctured. The similarities between the soot patterns on the tank walls at the punctures and the soot patterns on the outside walls of the tank indicated that the punctures occurred during the accident sequence before the fire. In addition, the size and shape of the punctures in the tank walls corresponded to the size and shape of the steel fork lift channels, indicating that the punctures were caused by the fork lift channels attached to other tanks. Therefore, the Safety Board concludes that the punctures on the three DOT 57 portable tanks transporting dicumyl peroxide were caused by the fork lift channels attached to other tanks

In 1988 the Safety Board investigated an accident in Collier County, Florida,[55] in which a cylinder containing poison gas was punctured by a steel plate attached to another cylinder. As a result of that investigation, the Safety Board issued the following safety recommendation to the Research and Special Programs Administration (RSPA) on March 23, 1990:

> I-90-7
>
> Require that attachments to cylinders be designed to reduce to a minimum the risk of puncturing other cylinders during transportation.

On September 24, 1990, RSPA responded to the Safety Board, stating that it intended to issue a notice of proposed rulemaking (NPRM) concerning standards that "will require cylinders to be designed in such a manner that punctures during transportation are kept to a minimum." Safety Recommendation I-90-7 was classified "Open--Acceptable Response" pending the issuance of a final rule; however, RSPA had not issued the NPRM as of September 3, 1992.

The accident near Calhoun demonstrates that the potential for punctures from appurtenances extends to all types of hazardous material containers. Therefore, the Safety Board believes that RSPA should expand its proposed rulemaking to require that attachments to all DOT-authorized hazardous material packagings be designed to minimize the risk of puncturing other packagings during an accident situation. As a result of the revised safety recommendation issued with this report, Safety Recommendation I-90-7 is classified as "Closed Acceptable Action/Superseded." Furthermore, the Safety Board believes that Hercules should modify the design of the fork lift truck channels on its tanks to minimize the risk of puncturing other tanks.

During the fire in the Calhoun accident, the 22 1/2-inch-diameter lids on 8 of the 10 portable tanks apparently functioned as intended, adequately relieving the rapid pressure buildup in the tanks during the decomposition of the dicumyl peroxide and preventing a violent overpressure rupture of any tank. The lids on the two remaining tanks probably did not pop off because the pressure inside those

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[55]Hazardous Materials Accident Report--*Puncture of a Cylinder Containing a Mixture of Methyl Bromide and Chloropicrin Following the Overturn of a Tractor-semitrailer, Collier County, Florida, November 30, 1988* (NTSB/HZM-90/01)

tanks did not increase significantly. A puncture hole in one tank's wall allowed its liquefied dicumyl peroxide to flow out. After the other tank fell on its side, its liquefied dicumyl peroxide flowed out through an opening where the 3 1/4-inch fusible plastic closure had been.

No plastic fusible closures were found during the postaccident examination of the tanks, and the Safety Board believes that the closures were consumed in the fire. While pressure may have popped off some 22 1/2-inch-diameter lids before the plastic fusible closures functioned, the closures probably melted first from the heat generated by the vehicle fire. The Safety Board is concerned that without the 22 1/2-inch-diameter pressure-relief lids, the internal overpressure during the rapid decomposition of the dicumyl peroxide would have ruptured the portable tanks.

During preaccident testing, Hercules found that in tanks with 22 1/2-inch-diameter pressure-relief openings, the internal pressure exceeded 140 psi but did not reach the calculated burst pressure of 247 psi. Hercules calculated that the 3 1/4-inch pressure-relief opening, which was double the size opening required by DOT regulations, would not prevent tank overpressure rupture because internal pressure would exceed 247 psi. Therefore, Hercules installed the plastic closures to meet the regulations but relied on the 22 1/2-inch-diameter pressure-relief openings to prevent overpressure ruptures.

The Safety Board believes that the DOT requirements are not adequate to ensure the safe venting of pressure buildup from the rapid decomposition of dicumyl peroxide within DOT 57 portable tanks. In addition, the Safety Board is concerned that other products that may be subject to rapid decomposition reaction are permitted to be transported in portable tanks for which current venting requirements may not be adequate. Because of the significant product volume transported in portable tanks and the potential hazards from a violent pressure rupture of tanks, the Safety Board believes the RSPA should revise the requirements for pressure-relief venting on DOT 57 portable tanks to ensure that the pressure-relief systems prevent overpressure rupture of tanks from a product rapid decomposition reaction.

Emergency Response to Dicumyl Peroxide Tank Fire

When the Charleston Volunteer Fire Department arrived at the accident site, firefighters observed the burning vehicle carrying the dicumyl peroxide and tried to extinguish the fire with water. No firefighters first attempted to determine whether the vehicle was carrying hazardous cargo or whether it was safe to apply water. Had the cargo been water reactive, the firefighters could have significantly increased the severity of the postaccident conditions. At minimum, first responders should try to identify the cargo from placards on the vehicle and to contact its driver for shipping papers or other documents.

At the time of the Calhoun accident, the Charleston firefighter-in-charge had received minimal training in fighting fires that involved hazardous materials. Because the Charleston Volunteer Fire Department is an all-volunteer organization, no assurance existed that a firefighter with basic hazardous materials training would be among those responding to an accident. Eleven members have since received a 12-hour basic hazardous materials course; however, the department has no plan to provide basic hazardous materials training for the other 19 volunteers While not every volunteer fire department may need a specialized hazardous materials response unit, the Safety Board is concerned that not all Charleston personnel have been provided with minimum hazardous materials training. The Safety Board believes that the Charleston Volunteer Fire Department should provide its personnel with the training necessary to identify hazardous materials in accidents, to recognize the immediate dangers posed, and to determine appropriate initial emergency response actions.

The Cleveland/Bradley County Emergency Management Agency hazardous materials team responded appropriately to the hazardous materials in this accident. This team first responded to the leaking tank reports and verified that the propane and the liquid nitrogen cargoes were not leaking. When informed about the vehicle fire involving dicumyl peroxide, they immediately went to that vehicle and obtained appropriate information from the driver about the hazardous material on board. They reported this information to the Charleston firefighters, who had already decided to let the fire burn itself out and to concentrate on control and containment.

CONCLUSIONS

Findings

1. Based on information available from witness statements, police accident reports, photographs, videotapes, and vehicle damage, neither the mechanical condition of the vehicles involved in the initial collisions nor the physical condition of the road were factors in the accident.

2. In the multiple-vehicle collisions near Calhoun, drivers responded to the sudden loss of visibility with varying reductions in speed.

3. The Tennessee Highway Patrol I-75 Fog Zone Contingency Plan does not ensure the prompt detection of fog or changes in its density.

4. Based on the European limited-visibility countermeasure system experience, a comprehensive U.S. system should include a combination of visibility sensors and traffic flow detectors that automatically activate traffic control devices when either hazardous conditions occur or traffic slows.

5. The 1992 Tennessee Department of Transportation and Tennessee Highway Patrol Plan of Action and the Surveillance and Response Plan did not include traffic flow disruption as a component and may not ensure the timely detection of hazardous limited-visibility conditions.

6. The use of police patrols to detect limited-visibility situations will not ensure their timely discovery.

7. Weather forecasting is not sufficiently accurate, comprehensive, or timely to predict that fog will form in a specific area.

8. The fog warning signs and flashing beacons installed by the Tennessee Department of Transportation were not sufficient to produce uniform driver behavior and were ineffective in part as warning devices in this accident because they did not consistently reflect actual conditions.

9. Based on the accidents discussed in this report, motorists are not provided with sufficient specific behavioral guidance on responding to limited-visibility situations.

10. Any one of a combination of meteorological and industrial effects may have influenced the formation, density, and subsequent movement of the fog on the day of the Calhoun accident.

11. The punctures on the three U.S. Department of Transportation specification 57 portable tanks transporting dicumyl peroxide were caused by the fork lift channels attached to other tanks.

12. Federal requirements are not adequate to ensure the safe venting of pressure build up from the rapid decomposition of dicumyl peroxide within U.S. Department of Transportation specification 57 portable tanks.

13. Although some Charleston Volunteer Fire Department personnel had received minimum hazardous materials training before the Calhoun accident, no assurance existed that a trained firefighter would be among those who responded to an incident involving hazardous materials.

Probable Cause

The National Transportation Safety Board determines that the probable cause of the multiple-vehicle collisions on I-75 near Calhoun, Tennessee, was drivers responding to the sudden loss of visibility by operating their vehicles at significantly varying speeds.

RECOMMENDATIONS

As a result of its investigation, the National Transportation Safety Board made the following recommendations:

--to the U. S. Department of Transportation:

> Incorporate fog and other limited-visibility condition countermeasures in demonstration projects of the Intelligent Vehicle Highway System program. (Class II, Priority Action) (H-92-86)

--to the Federal Highway Administration:

> Following completion of the National Cooperative Highway Research Program Project 20-5, Topic 23-12, "Reduced Visibility on the Highway," ensure the continued development of effective fog and other limited-visibility countermeasures and make information about these countermeasures available to States on a timely basis. (Class II, Priority Action) (H-92-87)

In cooperation with the National Highway Traffic Safety Administration, the American Association of Motor Vehicle Administrators, the American Automobile Association, and the American Driver and Traffic Safety Education Association, review and update driver license, educational, and remedial training materials to ensure that guidance for driving during limited-visibility conditions is uniform and complete and is included in commercial driver license materials. (Class II, Priority Action) (H-92-88)

--to the National Highway Traffic Safety Administration:

In cooperation with the Federal Highway Administration, the American Automobile Association, the American Association of Motor Vehicle Administrators, and the American Driver and Traffic Safety Education Association, review and update driver license, educational, and remedial training materials to ensure that guidance for driving during limited-visibility conditions is uniform and complete. (Class II, Priority Action) (H-92-89)

In cooperation with the American Association of Motor Vehicle Administrators, develop model test questions for licensing examinations on driving during limited-visibility conditions. (Class II, Priority Action) (H-92-90)

--to the Research and Special Programs Administration:

Require that attachments to all U.S. Department of Transportation-authorized hazardous materials packagings be designed to minimize the risk of puncturing other hazardous materials packagings during an accident situation. (Class II, Priority Action) (I-92-1)

Revise requirements for pressure-relief venting on U.S. Department of Transportation specification 57 portable tanks used to transport dicumyl peroxide and other products with similar rapid decomposition characteristics to ensure that the pressure-relief systems prevent overpressure rupture of tanks from a rapid product decomposition reaction. (Class II, Priority Action) (I-92-2)

--to the Tennessee Department of Transportation:

In cooperation with the Tennessee Highway Patrol, revise the 1992 Tennessee Department of Transportation and Tennessee Highway Patrol Plan of Action and the Surveillance and Response Plan. The plans should provide for the immediate detection of traffic flow disruption and fog, uniform driver response to reduce and maintain traffic speed in advance of and through the hazardous area, enforcement of countermeasures, and a public information and education program to ensure that motorists receive specific behavioral guidance for the fog-prone area. (Class II, Priority Action) (H-92-91)

--to the Tennessee Highway Patrol:

In cooperation with the Tennessee Department of Transportation, revise the 1992 Tennessee Department of Transportation and Tennessee Highway Patrol Plan of Action and the Surveillance and Response Plan. The plans should provide for the immediate detection of traffic flow disruption and fog, uniform driver response to reduce and maintain traffic speed in advance of and through the hazardous area, enforcement of countermeasures, and a public education program to ensure that motorists receive specific behavioral guidance for the fog-prone area. (Class II, Priority Action) (H-92-92)

--to the American Association of Motor Vehicle Administrators:

Notify your members of the circumstances of the accident on Interstate 75 near Calhoun, Tennessee, as discussed in this report. Also, develop inserts concerning countermeasures that motorists should consider when driving during fog and other limited-visibility conditions and advise your members to enclose such inserts with driver license renewals, motor vehicle registration renewals, and similar mailings. (Class II, Priority Action) (H-92-93)

In cooperation with the National Highway Traffic Safety Administration, the American Automobile Association, the Federal Highway Administration, and the American Driver and Traffic Safety Education Association, review and update driver license, educational, and remedial training materials to ensure that guidance for driving during limited-visibility conditions is uniform and complete. (Class II, Priority Action) (H-92-94)

In cooperation with the National Highway Traffic Safety Administration, develop model test questions for licensing examinations on driving during limited-visibility conditions. Provide this information to your members for inclusion in driver manuals. (Class II, Priority Action) (H-92-95)

--to Hercules, Incorporated:

Modify the design of the fork lift truck channels on U.S. Department of Transportation specification 57 portable tanks to minimize the risk of puncturing other portable tanks during an accident situation. (Class II, Priority Action) (I-92-3)

--to the Charleston Volunteer Fire Department:

Provide all personnel with the training necessary to identify hazardous materials in accidents, to recognize the immediate dangers posed, and to determine appropriate initial emergency response actions. (Class II, Priority Action) (I-92-4)

--to the American Automobile Association:

In cooperation with the Federal Highway Administration, the National Highway Traffic Safety Administration, the Association of Motor Vehicle Administrators, and the American Driver and Traffic Safety Education Association, review and update driver license, educational (including Triptik maps), and remedial training materials to ensure that guidance for driving during limited-visibility conditions is uniform and complete. (Class II, Priority Action) (H-92-96)

--to the American Driver and Traffic Safety Education Association:

In cooperation with the Federal Highway Administration, the National Traffic Safety Administration, the American Association of Motor Vehicle Administrators, and the American Automobile Association, review and update driver license, educational, and remedial training materials to ensure that guidance for driving during limited-visibility conditions is uniform and complete. (Class II, Priority Action) (H-92-97)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

CARL W. VOGT
Chairman

SUSAN M. COUGHLIN
Vice Chairman

JOHN K. LAUBER
Member

CHRISTOPHER A. HART
Member

JOHN A. HAMMERSCHMIDT
Member

September 28, 1992

Christopher A. Hart, Member, filed the following partial dissent:

Member Hart concurs in the report, probable cause, and recommendations, except that Safety Recommendation I-92-2 is too narrowly drawn and should stop after the words "prevent overpressure rupture of tanks."

CHRISTOPHER A. HART
Member

APPENDIXES

APPENDIX A

INVESTIGATION AND HEARING

Investigation

The National Transportation Safety Board was notified of this accident by news sources about 11:00 a.m. on December 11, 1990. A Board member and highway accident investigators were dispatched from the Washington, D.C., headquarters and arrived on scene about 10 p.m. Participating in the investigation were representatives from the Federal Highway Administration, Office of Motor Carrier Safety, Nashville, Tennessee; Tennessee Department of Transportation; Tennessee Department of Public Safety; Tennessee Emergency Management Agency; Tennessee Public Service Commission; Bradley County Sheriff's Department; McMinn County Sheriff's Department; Bradley County Emergency Management Coordinator; McMinn County Emergency Preparedness Coordinator; Athens Fire Department; McMinn County Emergency Medical Services; Hercules, Incorporated; Bowater Southern Division; and Olin Corporation.

Public Hearing

On April 24 and 25, 1991, the National Transportation Safety Board conducted a special public hearing in Knoxville, Tennessee. Sixteen experts from the private sector, universities, and public and private transportation authorities in the United States and Europe spoke on new technology and special programs to detect and to reduce fog-related accidents on limited access highways. They discussed these issues with a technical panel of Safety Board investigators, the Board of Inquiry, and each other. (See the following list of speakers and topics.)

Special Fog Hearing Speakers and Topics

Speaker	Topic
Dr. James Bradley National Oceanic and Atmospheric Administration National Weather Service RD-1, Box 105 Sterling, Virginia 22170	Characteristics of Fog Detection Devices
Mr. Robert Coleman National Weather Service Forecast Office (OM-1) Agricenter International 7777 Walnut Grove Road Memphis, Tennessee 38120-2198	Fog Forecasting
Mr. Carl Hayden, P.E. Highway Engineer Federal Highway Administration 400 7th Street, S.W. Washington, D.C. 20590	Federal Highway Administration Policies and Programs Concerning Highway Fog Issues

Mr. Richard N. Schwab Electrical Engineer, HRS-30 Federal Highway Administration Turner-Fairbanks Highway Research Center 6300 Georgetown Pike McLean, Virginia 22101-2296	Federal Highway Administration Policies and Programs Concerning Highway Fog Issues
Dr. Thomas Rockwell, Emeritus Ohio State University R & R Consulting 5709 Aspendal Drive Columbus, Ohio 43220	Driver Behavior During Limited Visibility Conditions
Dr. Raymond Lee Pennsylvania State University Meteorology Department 503 Walker Building University Park, Pennsylvania 16802	Meteorological Optics
Mr. Robert Dale, P.E. Director of Operations New Jersey Turnpike Authority P.O. Box 1121 New Brunswick, New Jersey 08903	New Jersey's Fog Policies and Countermeasures
Mr. Robert Lambert General Manager New Orleans Expressway Commission P.O. Box 7656 Metairie, Louisiana 70010	Fog Policies and Procedures on the Greater New Orleans Expressway
Mr. Frank Shepard Research Scientist Virginia Highway and Transportation Research Council P.O. Box 3817 Charlottesville, Virginia 22903	Virginia Countermeasures to Mitigate Fog Accidents
Mr. D. W. Lewis, P.E. Bridge Projects Manager South Carolina Department of Transportation P.O. Box 191 Columbus, South Carolina 29202	Polices and Procedures for Mitigating Fog Accidents on the Cooper River Bridge Project
Mr. James Norris Civil Engineering Director Tennessee Department of Transportation Suite 400 Jas. K. Polk Building Nashville, Tennessee 37243-0333	Tennessee Experiences with Fog Accident Countermeasures
Mr. Dan Julio, P.E. Local Governments Project Engineer Utah Department of Transportation Salt Lake City, Utah 84119	Utah Experiences with Fog Accident Countermeasures

Mr. Robert Binger, P.E. Deputy District Director for Maintenance and Operations CALTRANS-District 1352 W. Olive Avenue P.O. Box 12616 Fresno, California 93778	Highway Fog and California's Policies in Effecting Countermeasures
John Anderson Chief California Highway Patrol P.O. Box 942-898 Sacramento, California 94298	Highway Fog and California's Policies in Effecting Countermeasures
Mr. Job J. Klijnhout Transportation and Traffic Research Division Ministry of Transport and Public Works Boompjes 200 P.O. Box 1031 3000 BA Rotterdam The Netherlands	Experiences in theNetherlands and Europe
Dr. August Burgett, P.E Chief, Light Vehicle Dynamics and Simulation Division National Highway Traffic Safety Administration 400 7th Street S.W. Washington, D.C. 20590	Vehicle Lighting and Crash Avoidance

APPENDIX B

FATAL ACCIDENT CLUSTER VEHICLE DESCRIPTIONS

The first southbound accident cluster involved a 1991 Oldsmobile Delta 88 and a 1989 Freightliner tractor-semitrailer and resulted in two fatalities. A 1983 Ford F-100 pickup truck and a 1990 Freightliner tractor-semitrailer were also involved in this fatal accident cluster.

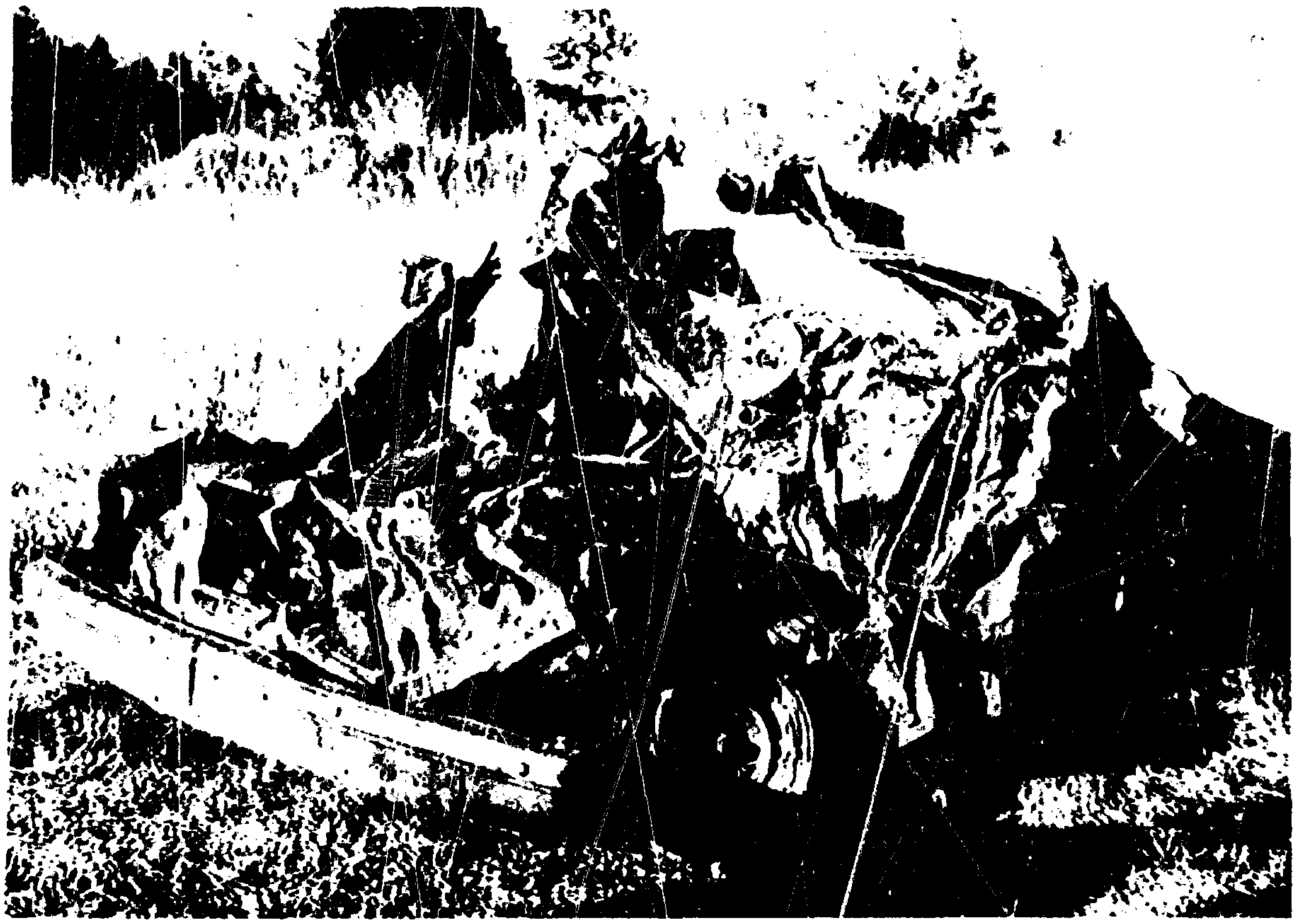
The 1991 Oldsmobile Delta 88 in which the driver and the front-seat passenger were fatally injured.

The second southbound fatal accident cluster involved a 1987 Mazda B2000 pickup truck, a 1986 Mercedes 420 SEL 4-door sedan, a 1960 GMC 4104 intercity bus converted into a motor home (47-year-old male driver received fatal injuries), a 1983 Chevrolet C10 pickup truck, a 1982 GMC C30 pickup truck in combination with a flat-bed utility trailer, and a 1984 Chevrolet C10 pickup truck (41-year-old female driver received fatal injuries).

The front of the GMC 4104 intercity bus was incinerated, a small section of its rear remained, the roof was burned, and only the crossmembers remained. The left rear area, including the third and fourth window, and the rear window were all that remained to identify the vehicle as a bus.

The rear and only remaining section of the 1960 GMC intercity bus, converted into a motor home, in which the driver was fatally injured.

The burned 1984 Chevrolet C10 pickup truck showed frontal impact damage to the occupant compartment and rear impact damage that included the pickup bed and a ruptured full tank. The hood was not present, the firewall to the rear of the cab was displaced rearward, the roof was collapsed downward and rearward, and the forward bed rail was bent rearward. The instrument panel was forced rearward to the middle of the seat, the left side of the body was crushed inward, and the rear bumper was twisted and displaced downward.



The 1984 Chevrolet C10 pickup truck in which the driver was fatally injured.

The third southbound fatal accident cluster had four fatalities and involved a 1980 White cab-over-engine (COE) tractor-semitrailer (52-year-old male driver received fatal injuries), a 1988 GMC tractor-semitrailer, a 1984 Lincoln Town Car 4-door sedan (60-year-old male driver received fatal injuries), a 1985 Freightliner COE tractor-semitrailer (38-year-old male driver received fatal injuries), a 1984 Chrysler 5th Avenue 4-door sedan, a 1981 Ford Thunderbird 2-door sedan, a 1988 Volvo tractor-semitrailer (30-year-old male driver received fatal injuries), a 1990 Peterbilt tractor-semitrailer, and a 1988 Holiday Rambler motor home that towed a four-wheel vehicle.

The White COE tractor had been pulling a semitrailer loaded with rolls of paper. The Lincoln came to rest under the rear of the Freightliner tractor-semitrailer. When White COE tractor struck the rear of the Lincoln, the tractor was destroyed by fire. All that remained were the frame, axles, rear wheel rims, and engine. Impact damage to the radiator indicated that it had been pushed rearward into the fan and pulleys. The cab was not present, although its metal melted and was distributed over the engine and frame. The frame from the front crossmember to the end of the engine block was displaced 3 feet to the right. Fire destroyed the White tractor COE and the Lincoln, and their drivers were trapped inside.

The 1980 White COE tractor in which the driver was fatally injured.

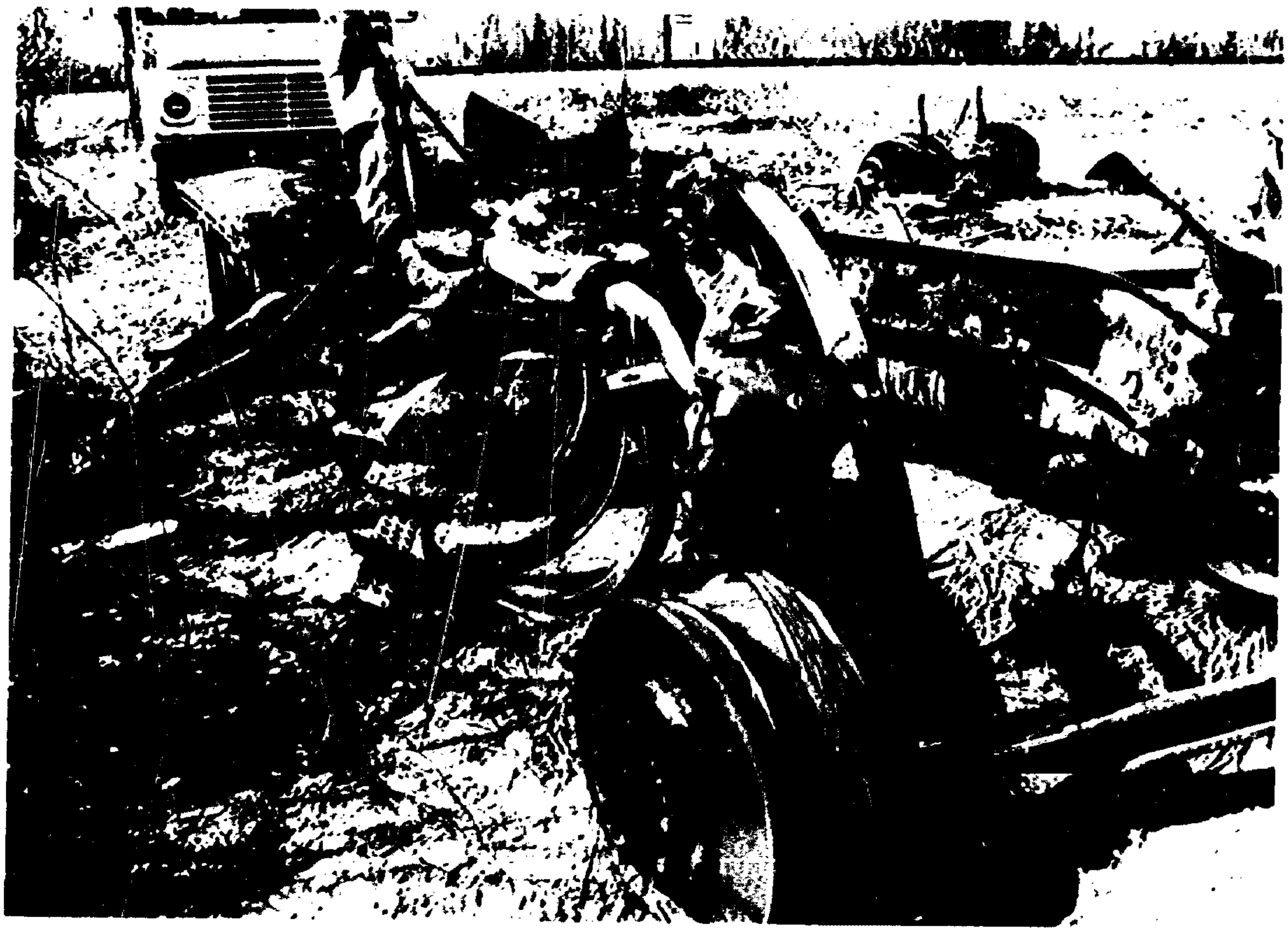
The 1984 Lincoln Town Car was burned, except for the rear bumper. Crush damage extended inward on the left side to the center of the driver seat. The full front of the vehicle was displaced to the left, the impact damage of the left front extended rearward to the firewall, and the hood was folded rearward.

The 1984 Lincoln Town Car in which the driver was fatally injured.

The Freightliner had been pulling a semitrailer loaded with household cleaning supplies when it collided with an unoccupied, parked 1984 Chrysler that burned after it was forced under the rear of a Volvo tractor-semitrailer. The tractor was destroyed by the fire that melted the cab onto the engine. Its curved and misaligned frame with the axles, rear wheel rims, and engine were all that remained of the tractor.

The 1985 Freightliner in which the driver was fatally injured.

The Volvo had been pulling a semitrailer loaded with automobile motor mounts when it collided with the rear of the Peterbilt tractor-semitrailer. Fire destroyed the Volvo and its cab was melted over the frame. The Volvo's left-side frame and leaf spring on the right side were folded over the right front wheel hub. Located 10 feet from the front of the frame, the crossmember had separated from the left side of the frame and was forced rearward 2 feet. The Volvo underrode the Peterbilt's semitrailer with such force that it separated the trailer's rear tandem axles from under the trailer. The engine was not present; however, the front trailer floor and pin that fits into the fifth wheel were attached to the tractor's fifth wheel.



The 1988 Volvo tractor in which the driver was fatally injured.

The fourth southbound fatal accident cluster had two fatalities and involved a 1987 Chevrolet Blazer 2-door sedan, a 1986 Mack 3-axle straight body truck, a 1990 International tractor-semitrailer, a 1991 Toyota Camry 4-door sedan, a 1986 Chevrolet Celebrity 4-door sedan, a 1977 Oldsmobile Delta 88 4-door sedan, a 1985 Chevrolet S-10 pickup truck, a 1987 Chevrolet Silverado pickup truck (52-year-old-female passenger received fatal injuries), a 1982 International COE tractor-semitrailer, a 1990 Ford Ranger pickup truck, a 1990 Volvo 740 4-door sedan, a 1989 Dodge Shadow 2-door sedan (58-year-old-female passenger received fatal injuries), a 1985 Chevrolet Celebrity 4-door sedan, a 1989 Buick LeSabre 4-door sedan, a 1980 Chevrolet Camaro 2-door sedan, a 1985 Nissan Sentra 2-door sedan, and a 1986 Chevrolet Citation 2-door sedan.

The Silverado sustained impact damage to the entire right headlight area that extended rearward, totally involving the operating compartment, when it collided with the rear of the International tractor-semitrailer. The Silverado's dashboard and firewall on the right side were crushed rearward, and the right A-pillar and door frame were displaced rearward. No fire damage was present.

The 1987 Chevrolet Silverado
in which the front-seat passenger was fatally injured.

The 1989 Shadow had impact damage below the rear window that extended into the trunk. Damage on the right front side extended the vehicle's full length and inward to its left side for the vehicle's width. The vehicle showed major fire damage.

The 1989 Dodge Shadow in which the front-seat passenger was fatally injured.

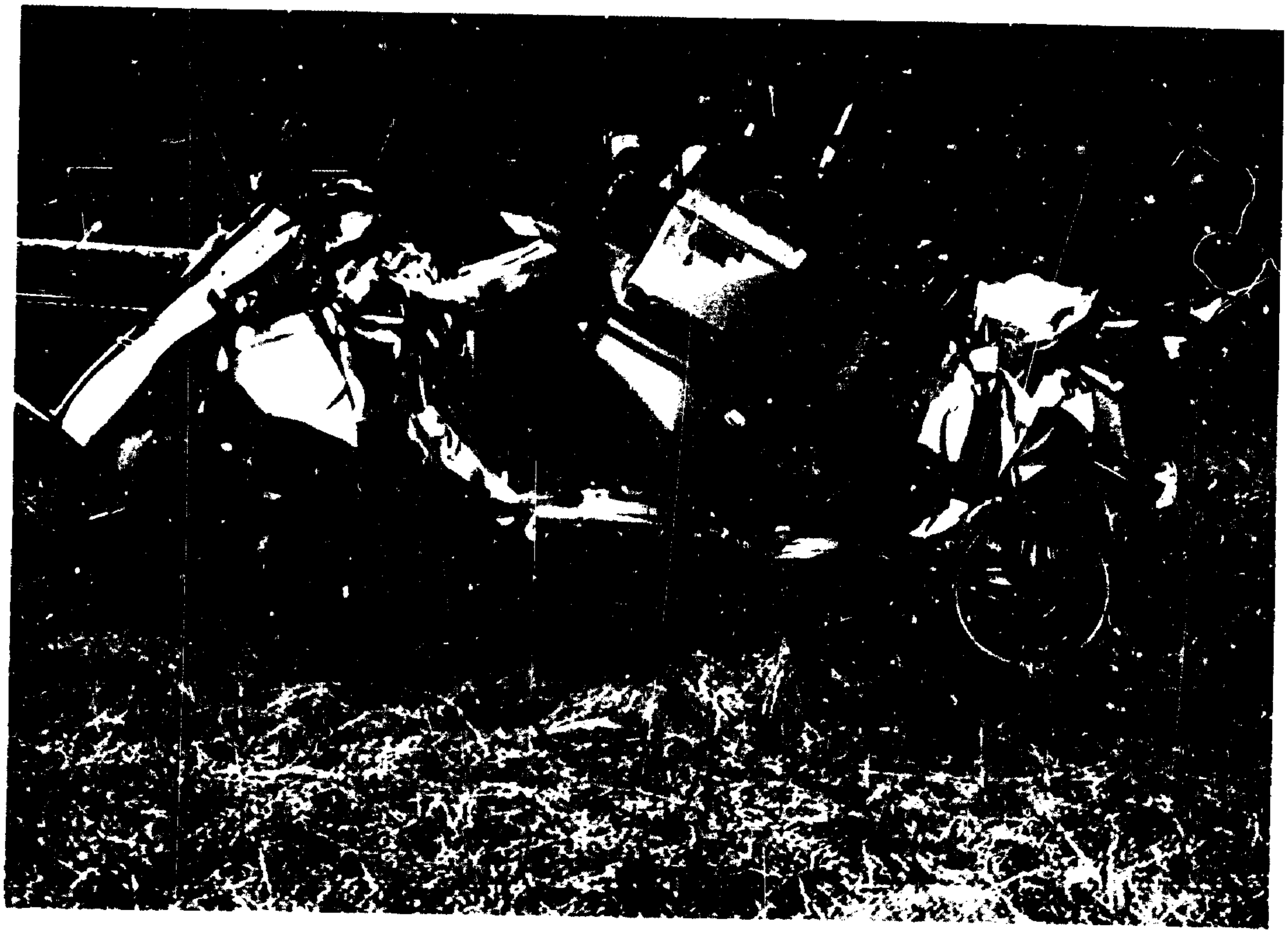
The first northbound fatal accident cluster involved a 1987 Mack tractor-tank trailer (liquid nitrogen) combination, a 1989 Chevrolet Astro minivan (33-year-old female driver received fatal injuries), and a 1990 Nissan pickup truck.

The Astro struck the rear of the tank trailer and was damaged from the front bumper to the windshield, with the hood folded rearward. Both A-pillars were displaced rearward, and the roof above the front seats was displaced upward. The vehicle showed moderate impact damage to the rear doors and recovery damage to the rear bumper where it had been lifted.

The 1989 Astro minivan in which the driver was fatally injured.

The second northbound fatal accident cluster involved a 1988 Peterbilt tractor-tank trailer (liquefied petroleum gas -- propane) combination, a 1982 Toyota Corolla 2-door sedan (51-year-old-female driver received fatal injuries), and a 1989 Ford tractor-double combination trailers.

The Corolla was crushed between the tractor-semitrailers, sustained impact damage to the front and rear, and was destroyed.



The 1982 Toyota Corolla 2-door sedan
in which the driver was fatally injured.

APPENDIX C

KEY TO POSTACCIDENT LOCATION OF VEHICLES

I-75 Southbound

1	1990 Freightliner tractor-semitrailer
2	1989 Freightliner tractor-semitrailer
3	1991 Oldsmobile Delta 88 (fatals, driver and passenger)
4	1984 Freightliner tractor-semitrailer
5	1983 Ford F-100 pickup truck
6	1981 GMC tractor-semitrailer
7	1981 GMC cab over tractor
8	1979 Oldsmobile Delta 88
9	1988 Lincoln
10	1983 Datsun Maxima
11	1988 Holiday Rambler motor home
12	1987 Chevrolet Blazer
13	1990 Peterbilt tractor-semitrailer
14	1988 Volvo tractor-semitrailer (fatal, driver)
15	1981 Ford Thunderbird
16	1984 Chrysler 5th Avenue (not on diagram)
17	1982 GMC truck
18	1985 Freightliner tractor-semitrailer (fatal, driver)
19	1984 Lincoln (fatal, driver)
20	1983 Chevrolet pickup truck
21	1960 GMC converted bus motor home (fatal, driver)
22	1986 Mercedes 420 SEL
23	1987 Mazda pickup truck
24	1983 Dodge Cara-Van (not on diagram)
25	1989 Chevrolet Corsica (not on diagram)
26	1987 Oldsmobile (not on diagram)
27	1991 Honda Accord (not on diagram)
28	1989 Ford Bronco (not on diagram)
29	1984 Chevrolet pickup truck (not on diagram) (fatal, driver)
30	1980 Chevrolet pickup truck (not on diagram)
31	1988 GMC tractor-semitrailer
32	1980 White tractor-semitrailer (fatal, driver)
33	1990 Chevrolet stationwagon
34	1989 Ford Escort
35	1990 Cadillac
36	1985 International tractor-semitrailer
37	1987 Chevrolet truck
38	1989 GMC pickup truck
39	Shaw tractor-semitrailer (noncontact)
40	McKinnon Bridge tractor-semitrailer (noncontact)
41	Penske tractor-semitrailer (noncontact)
42	1978 Ford pickup truck
43	Beal Produce truck (noncontact)
44	Dodge Cara-Van
45	1979 Cadillac
46	1988 Ford pickup truck
47	1985 Mercury Marquis
48	1990 Volvo 740

49	1991 Ford Econoline van
50	1989 Buick LeSabre
51	1985 Chevrolet Celebrity
52	1980 Chevrolet Camaro
53	1989 Dodge Shadow (fatal, passenger)
54	1990 Ford Ranger pickup truck
55	1982 International tractor-semitrailer
56	1985 Nissan Sentra
57	1984 Pontiac
58	1989 GMC Club Cab pickup truck
59	1987 Chevrolet pickup truck (fatal, passenger)
60	Camper top from vehicle # 16
61	1985 Chevrolet pickup truck
62	1986 Chevrolet Cavalier
63	1990 International tractor-semitrailer
64	1987 Chevrolet Blazer
65	1977 Oldsmobile Delta 88
66	1986 Chevrolet Celebrity
67	1991 Toyota Camry
68	1986 Mack truck
69	Nissan Pathfinder (noncontact)
70	1985 Ford Escort
71	Dodge van (noncontact)
72	1990 Kenworth tractor-semitrailer
73	1983 Oldsmobile Delta 88
74	1986 Chevrolet pickup truck
75	1990 Dodge Cara-Van
76	1990 Ford Bronco
77	1985 Ford tractor-semitrailer
78	1983 Ford truck
79	1991 Chevrolet Blazer
80	1987 GMC truck

I-75 Northbound

1	1987 Honda
2	1987 Ford Escort
3	1982 Toyota
4	1990 Pontiac Sunbird
5	1989 Oldsmobile Delta 88
6	1988 White tractor-semitrailer
7	1971 Ford motor home
8	1987 Chevrolet Caprice
9	1990 International tractor-semitrailer
10	1984 Freightliner tractor-semitrailer
11	1986 Pontiac 6000
12	1989 Toyota pickup truck
13	1986 Chevrolet EL Camino
14	1989 Freightliner tractor-semitrailer
15	1980 International tractor-semitrailer
16	1989 Freightliner tractor-semitrailer
17	1980 Chevrolet C10 pickup truck
18	1983 Audi 4000
19	1980 International tractor-semitrailer

20	1987 Mack tractor-cargo tank-semitrailer
21	1978 Oldsmobile Cutlass
22	1989 Chevrolet Astro van (fatal, driver)
23	1990 Nissan pickup truck
24	1986 Isuzu
25	1988 Peterbilt tractor-cargo tank-semitrailer
26	1982 Toyota Corolla (fatal, driver)
27	1989 Ford tractor-semitrailer

APPENDIX D

FATAL ACCIDENT CLUSTERS
SAFETY BELT USAGE
OCCUPANT AND INJURY INFORMATION

Southbound fatal accident cluster number one involved five vehicles, two fatalities, and two injured drivers.

	Vehicle	Belt Use	Driver Age	Driver Sex	Passenger Age	Passenger Sex	AIS	Description of Injury
1	1984 Freightliner tractor	N	48	M			1	Facial contusions
2	1991 Oldsmobile Delta 88	Y	69	M			5	Fatal, second and third degree burns over 90 percent of total body surface, (TBS)
2	1991 Oldsmobile Delta 88				67	F		Fatal, incineration
3	1989 Freightliner	Y	35	M			1	Bruises of extremities
4	1983 Ford F-100	Unk.	52	M				No reported injuries
5	1990 Freightliner Tractor-semitrailer	Y	35	M				No reported injuries

Southbound fatal accident cluster number two involved six vehicles, two fatalities, two injured drivers, and four injured passengers.

	Vehicle	Belt Use	Driver Age	Driver Sex	Passenger Age	Passenger Sex	AIS	Description of Injury
1	1987 Mazda Pickup truck	Y	38	M			1	Bruise, left thigh
1	1987 Mazda Pickup truck	Y			31	F	1	Abrasions, Contusions
2	1986 Mercedes 420 SEL	N	38	M			3	Dislocation of right hip with acetabular rim and femoral head fracture
3	1960 GMC Motor home	N	47	M			5	Fatal, second and third degree burns over 90 percent of TBS
3	1960 GMC Motor home	N			35	F	2	Second and third degree burns of both feet
3	1960 GMC Motor home	N			14	M	2	Minor compression fracture of thoracic vertebral bodies of T7 and T8
4	1983 Chevrolet C10	Y	27	M				No reported injuries
5	1982 GMC C30	Y	29	M				No reported injuries
5	1982 GMC C30	Y			34	M	1	Facial laceration and contusions
6	1984 Chevrolet C10 Pickup truck	Unk.	41	F			5	Fatal, incineration

Southbound fatal accident cluster number three involved nine vehicles, four fatalities, and one injured driver.

	Vehicle	Belt Use	Driver Age	Driver Sex	Passenger Age	Passenger Sex	AIS	Description of Injury
1	1980 White Tractor	Unk.	52	M			5	Fatal, incineration
2	1988 GMC Tractor	Y	52	M				No reported injuries
3	1984 Lincoln Town Car	Unk.	60	M			5	Fatal, incineration
4	1985 Freightliner Tractor-semitrailer	Unk.	38	M			5	Fatal, incineration
5	1984 Chrysler 5th Avenue	N.A.[1]	18	F				(Vehicle unoccupied)
6	1981 Ford Thunderbird	Y	45	M			1	Facial lacerations and contusions
7	1988 Volvo Tractor-semitrailer	Unk.	30	M			5	Fatal, incineration
8	1990 Peterbilt Tractor	Y	24	M				No reported injuries
9	1988 Holiday Motor home	N.A.	70	M				(Vehicle unoccupied)

[1]Information not available.

Southbound fatal accident cluster number four involved 17 vehicles, 2 fatalities, 9 injured drivers, and 5 injured passengers.

	Vehicle	Belt Use	Driver Age	Driver Sex	Passenger Age	Passenger Sex	AIS	Description of Injury
1	1987 Chevrolet Blazer	Y	34	F				No reported injuries
2	1986 Mack Tractor	N	37	M				No reported injuries
3	1990 International Tractor	Y	53	M				No reported injuries
4	1991 Toyota Camry	Y	24	M				No reported injuries
5	1986 Chevrolet Celebrity	Y	34	M				No reported injuries
6	1977 Oldsmobile Delta 88	Y	53	M			2	Fractured left tibia, chin laceration
7	1985 Chevrolet S-10	Y	54	M				No reported injuries
7	1985 Chevrolet S-10	Y			54	F	4	Subdural hematoma
8	1987 Chevrolet Silverado pickup truck	Y	63	M			2	Compression fracture 4th thoracic vertebra, abrasions, contusions
8	1985 Chevrolet Silverado pickup truck	Y			52	F	3	Fatal, crushed right, shoulder, abdominal hemorrhage, Fractured right lower leg
9	1982 International tractor	N	48	M			2	No reported injuries

10	1990 Ford Ranger	Y	58	M			2	Partial amputation of left little and ring finger, fractured left tibia
11	1990 Volvo, #740	Y	70	M			3	Concussion, comminuted fracture left humerus
11	1990 Volvo, #740	Y			69	F	1	Multiple bruises
12	1989 Dodge Shadow	Unk.	67	M			5	Right lung contusion with tension pneumothorax, open fracture of the right ulna, myocardium contusion
12	1989 Dodge Shadow	Unk.			58	F	3	Fatal, abdominal hemorrhage, fractured lower left ribs
13	1985 Chevrolet Celebrity	Y	71	M			2	Fractured left clavicle, right tho rib, right radial styloid (wrist)
13	1985 Chevrolet Celebrity	Y			67	F	2	Blunt chest trauma, fractured sternum
14	1989 Buick LeSabre	Y	42	M			1	Fractured right 5th rib
15	1980 Chevrolet Camaro	N	23	F			1	Blunt chest trauma, forehead abrasions
15	1980 Chevrolet Camaro	Child seat			2mo.	F		Routine medical examination
15	1980 Chevrolet Camaro	N			21	M	1	Soft tissue injury
15	1980 Chevrolet Camaro	N			16	F	1	Laceration of scalp
16	1985 Nissan Sentra	Y	25	M				No reported injuries
16	1985 Nissan Sentra	Y			66	M		Routine medical examination
17	1986 Chevrolet	Y	21	M			1	Bruises and abrasions

Northbound fatal accident cluster number one involved seven vehicles, one fatality, two injured drivers, and one injured passenger.

	Vehicle	Belt Use	Driver Age	Driver Sex	Passenger Age	Passenger Sex	AIS	Description of Injury
1	1983 Audi 4000	Y	35	M				No reported injuries
2	1980 International Tractor-semitrailer	Y	37	M				No reported injuries
3	1987 Mack Tractor-cargo tank-semitrailer	Y	41	M				No reported injuries
4	1978 Oldsmobile Cutlass	N	21	M			2	Closed fracture of the right hip
5	1989 Chevrolet Astro van	N	33	F			5	Fatal, fractured neck laceration of the chin contusion on the right side of the neck, fractured right ankle
6	1990 Nissan Pickup truck	Y	67	M			2	Fractured sternum
6	1990 Nissan Pickup truck	Y			69	F	2	Fractured right tibia and fourth patella, fractured and fifth metacarpus
7	1986 Isuzu	Y	23	F				No reported injuries

Northbound fatal accident cluster number two involved three vehicles, one fatality, one injured driver, and one injured passenger.

	Vehicle	Belt Use	Driver Age	Driver Sex	Passenger Age	Passenger Sex	AIS	Description of Injury
1	1988 Peterbilt Tractor-cargo tank-semitrailer	N	33	M				No reported injuries
2	1982 Toyota Corolla	N	51	F			4	Fatal, contusion left chest and abdominal wall, amputation of both legs
2	1982 Toyota Corolla	N			11	F	3	Comminuted fracture of the right femur and tibia
3	1989 Ford Tractor-semitrailer (double unit)	Y	60	M			1	Lumbar strain

APPENDIX E

ABBREVIATED INJURY SCALE

Southbound Injury Classifications - Abbreviated Injury Scale[1]

Description	Driver(s)	Passenger(s)	Total
Minor	15	6	21
Moderate	4	3	7
Serious	3	3	6
Severe	0	1	1
Critical	8	1	9
Maximum	0	0	0
Unknown	0	0	0
Total	30	14	44

Northbound Injury Classifications - Abbreviated Injury Scale

Description	Driver(s)	Passenger(s)	Total
Minor	3	0	3
Moderate	3	1	4
Serious	0	1	1
Severe	1	0	1
Critical	1	0	1
Maximum	0	0	0
Unknown	0	0	0
Total	8	2	10

[1]AIS is a standardized coding system established by the Association for the Advancement of Automotive Medicine for assessing the severity of impact injuries. Injuries were coded according to the revised 1990 AIS.

FATALITIES DURING FOG CONDITIONS ON SELECTED HIGHWAYS*

Year	Interstate	Rural Primary	Rural Min. Art.	Rural Maj. Coll.	Rural Local Road	Urban Frwy./Expwy.	Urban Other Prin. Art.	All Others	Total
1991	67	122	93	131	59	32	39	124	667
1990	84	92	127	152	69	22	51	121	718
1989	103	134	127	144	66	29	44	136	783
1988	81	116	98	115	51	16	44	101	622
1987	51	101	92	130	64	20	37	91	586
1986**	68							662	730
1985**	96							638	734
1984**	88							659	747
1983**	48							436	484
1982**	68							665	733
									6,804

* National Highway Traffic Safety Administration Fatal Accident Reporting System data when fog conditions were present on the road.

** With the exception of Interstate highways, road function classes for 1982-86 do not compare with 1987-91 because of changes in coding the data.

APPENDIX G

SUMMARY OF NCHRP PROJECT "REDUCED VISIBILITY ON THE HIGHWAY"

Final (11-12-91)

NCHRP PROJECT 20-5
TOPIC 23-12

SCOPE

The most notable contributor to reduced visibility on highways is fog. The meteorology and optics of fog are well understood, but driver perception and behavior in fog are not. Fog generally occurs over relatively large areas, but there is great variability in its density. This variability is a major highway safety issue, and almost every year at least one state has a spectacular multi-vehicle accident as a consequence of reduced visibility. While there have been technological advances in fog detection associated with airports, there has been limited application to detection of fog on highways. There has also been limited evaluation of driver performance in response to fog countermeasures.

A number of countermeasures have been tested and/or implemented to overcome the problems caused by fog and other conditions of reduced visibility. These include forecasting and detection, motorist information, traffic control, visibility enhancement, and fog abatement. Although much has been learned, the problems caused by fog still remain.

The synthesis will:

- briefly summarize the meteorology of fog, forecasting and detection.
- briefly summarize the state of knowledge regarding driver perception and behavior in fog.
- report the current state of the practice of fog countermeasures, including evaluations of these countermeasures where available. In addition, the state of the practice review will include previous experiences that proved unsuccessful.
- assess the applicability of fog countermeasures to other reduced visibility conditions such as smoke, dust, rain, snow, and other traffic problems.

APPENDIX H

ACCIDENTS ON I-75
BRADLEY-McMINN COUNTIES
FROM MP 32 TO MP 38

Year	ADT	Total Acc.	P.D. Acc.	Injury Acc.	Fatal Acc.	Acc. Rate	S.W. Rate
1974	13,040	12	7	4	1	0.66	0.40
1975	13,040	20	10	9	1	1.10	0.40
1976	17,270	15	9	6	0	0.62	0.40
1977	16,600	11	10	0	1	0.47	0.40
1978	17,030	32	15	17	0	1.34	0.40
1979	15,390	18	12	5	1	0.84	0.40
1980	14,070	19	18	1	0	0.97	0.56
1981	15,600	17	13	3	1	0.78	0.54
1982	15,160	10	5	5	0	0.47	0.45
1983	16,020	12	11	1	0	0.54	0.42
1984	17,390	13	10	3	0	0.53	0.42
1985	17,880	31	19	10	2	1.24	0.39
1986	22,390	27	20	7	0	0.86	0.55
1987	25,150	23	17	6	0	0.65	0.50
1988	25,030	32	19	12	1	0.91	0.45

APPENDIX I

PREVIOUS SAFETY RECOMMENDATIONS

As a result of various accident investigations in the 1970s, the Safety Board issued recommendations to the National Highway Traffic Safety Administration (NHTSA) concerning driver instruction and education for limited-visibility situations.

<u>H-71-017</u>

Initiate (through an appropriate demonstration project) a program and procedures for minimizing the likelihood of catastrophic chain-reaction collisions on high-speed, multilaned highways in adverse weather or visibility conditions; such program to consider, among others, requirements to: (1) segregate heavy vehicles from light vehicles by assigned use of lanes whenever safe speed is below posted speed; (2) forbid overtaking and passing by heavy vehicles; (3) use of four-way flashers by all vehicles; (4) prohibit stopping on the traveled portion of highways (unless conditions will not permit otherwise); and (5) evacuate stopped vehicles under the certain conditions.

<u>H-72-053</u>

Recommend to driver education instructors the need to stress in the teaching of drivers that there is no single solution to the highway fog problem, and point out the need to avoid or discontinue highway use until conditions warrant safe travel.

<u>H-75-008</u>

Modify Federal Highway Traffic Safety Standard No. 4, "Driver Education," to include more definitive information relative to reduced-visibility driving. This recommendation was also made by the Safety Board in its special study, "Reduced Visibility (Fog) Accidents on Limited-Access Highways," issued in 1972.

<u>H-81-026</u>

Consider the circumstances of and other similar limited-visibility accidents and develop a strategy such as that recommended in Safety Board recommendation H-71-017 for inclusion in highway safety program standard No. 4, "Driver Education," to inform motorists faced with adverse, limited-visibility driving conditions about the safest actions to take to protect themselves from injury.

NHTSA responded to these recommendations, stating:

> We are preparing an article on reduced visibility driving for the Journal of Traffic Safety Education... NHTSA developed a safe performance curriculum for secondary school driver education which includes a modular on limited visibility and advises discontinuing driving when visibility is severely reduced...NHTSA is emphasizing speed enforcement in manuals, policy documents and other guidance materials which is a responsibility of the States. Nevertheless NHTSA will continue to encourage the States to consider this problem area in developing their annual highway safety program. (1973)
>
> NHTSA has agreed to consider inclusion of reduced visibility driving information in HSPS 4 "Driver Education" when it is revised. (1977)
>
> We asked the States to consider this problem in developing their highway safety programs. We are not considering any further action, except to distribute to the States copies of your most recent "fog" accident report. We have done as much as we can considering the state-of-the-art. We have avoided making any recommendation about different vehicle types using certain lanes when entering areas of limited visibility. Educating the average motorist about various procedures to follow under the many conditions where fog might be encountered would be difficult. Enforcement of assigned lanes and prohibited overtaking and passing would be next to impossible....
>
> While we appreciate providing some type of uniform guidance to drivers encountering limited visibility, I do not believe a need has been demonstrated to create a new or innovative approach to deal with the problem, beyond the efforts we reported to you in our February 9, 1982, letter. Data collected by our fatal accident reporting system (FARS) has enabled us to determine that only between 1 and 2 percent of the fatal crashes occur because of drivers encountering a limited visibility driving situation. In fact, the 1980 FARS report clearly points out that fog, smoke, and blowing sand or dust accounted for only 1.8 percent of all fatal crashes, whereas 98 percent of the fatally injured passenger car occupants were not using restraint devices and 42 percent of the drivers with known blood alcohol test results in fatal accidents were intoxicated. If any research or data becomes available which would provide material for updating the article, "A Crying Need for Fog Highway Safety Education," we will consider making use of it. We shall continue to monitor this safety issue and provide information to the public as it becomes available....

> We agree that guidance to the public concerning limited visibility situations is essential to safe driving. A review of widely used high school driver education textbooks and State driver license manuals indicates that procedures for driving in adverse weather conditions are discussed. Also, NHTSA has developed and distributed nationwide a publication entitled "Safe Driving in Winter," which provides drivers with tips and ques for winter driving, including limited visibility situations. Enclosed for your information are the following items: (1) excerpts from selected driver education textbooks; (2) excerpts from information contained in the driving manuals used in Illinois and Maryland; (3) the discussion on limited visibility contained in the safe performance text; and (4) a copy of the publication "Safe Driving in Winter." (1982)

Based on the actions described by NHTSA, the Safety Board, on August 17, 1983, classified Safety Recommendations H-71-017, H-75-008, and H-81-026 "Closed--Acceptable Action." Further, on January 1, 1980, the Safety Board classified Safety Recommendation H-72-053 "Closed--Acceptable Action."