

Rupture of Hazardous Liquid Pipeline
With Release and Ignition of Propane
Carmichael, Mississippi
November 1, 2007



Accident Report
NTSB/PAR-09/01
PB2009-916501



**National
Transportation
Safety Board**

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**National
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Safety Board**

490 L'Enfant Plaza, S.W.
Washington, D.C. 20594

National Transportation Safety Board. 2009. *Rupture of Hazardous Liquid Pipeline With Release and Ignition of Propane, Carmichael, Mississippi, November 1, 2007. Pipeline Accident Report NTSB/PAR-09/01.* Washington, DC.

Abstract: On November 1, 2007, at 10:35:02 a.m. central daylight time, a 12-inch-diameter pipeline segment operated by Dixie Pipeline Company was transporting liquid propane at about 1,405 pounds per square inch, gauge, when it ruptured in a rural area near Carmichael, Mississippi. The resulting gas cloud expanded over nearby homes and ignited, creating a large fireball that was heard and seen from miles away. About 10,253 barrels (430,626 gallons) of propane were released. As a result of the ensuing fire, two people were killed and seven people sustained minor injuries. Four houses were destroyed, and several others were damaged. About 71.4 acres of grassland and woodland were burned. Dixie Pipeline Company reported that property damage resulting from the accident, including the loss of product, was \$3,377,247.

The safety issues identified in this accident are the failure mechanisms and safety of low-frequency electric resistance welded pipe, the adequacy of Dixie Pipeline Company's public education program, the adequacy of federal pipeline safety regulations and oversight exercised by the Pipeline and Hazardous Materials Safety Administration of pipeline operators' public education and emergency responder outreach programs, and emergency communications in Clarke County, Mississippi.

As a result of the investigation of this accident, the National Transportation Safety Board makes recommendations to the Pipeline and Hazardous Materials Safety Administration, the Dixie Pipeline Company, the American Petroleum Institute, and the Clarke County Board of Supervisors.

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Acronyms and Abbreviations

API	American Petroleum Institute
API RP 1162	API Recommended Practice 1162
CFR	<i>Code of Federal Regulations</i>
CVFD	Carmichael Volunteer Fire Department
Dixie	Dixie Pipeline Company
DOT	U.S. Department of Transportation
Enterprise	Enterprise Products Operating
ERW	Electric resistance welded
GE	General Electric
Hunt	Hunt Crude Oil Supply Company
Magpie	Magpie Systems Inc.
NTSB	National Transportation Safety Board
Paradigm	Paradigm Alliance, Inc.
PHMSA	Pipeline and Hazardous Materials Safety Administration
psi	pounds per square inch
psig	pounds per square inch, gauge
SCADA	Supervisory control and data acquisition
Stork	Stork Metallurgical Consultants

Executive Summary

On November 1, 2007, at 10:35:02 a.m. central daylight time, a 12-inch-diameter pipeline segment operated by Dixie Pipeline Company was transporting liquid propane at about 1,405 pounds per square inch, gauge, when it ruptured in a rural area near Carmichael, Mississippi. The resulting gas cloud expanded over nearby homes and ignited, creating a large fireball that was heard and seen from miles away. About 10,253 barrels (430,626 gallons) of propane were released. As a result of the ensuing fire, two people were killed and seven people sustained minor injuries. Four houses were destroyed, and several others were damaged. About 71.4 acres of grassland and woodland were burned. Dixie Pipeline Company reported that property damages resulting from the accident, including the loss of product, were \$3,377,247.

The National Transportation Safety Board determines that the probable cause of the November 1, 2007, rupture of the liquid propane pipeline operated by Dixie Pipeline Company near Carmichael, Mississippi, was the failure of a weld that caused the pipe to fracture along the longitudinal seam weld, a portion of the upstream girth weld, and portions of the adjacent pipe joints.

The following safety issues were identified as a result of the investigation of this accident:

- The failure mechanisms and safety of low-frequency electric resistance welded pipe,
- The adequacy of Dixie Pipeline Company's public education program,
- The adequacy of federal pipeline safety regulations and oversight exercised by the Pipeline and Hazardous Materials Safety Administration of pipeline operators' public education and emergency responder outreach programs, and
- Emergency communications in Clarke County, Mississippi.

Safety recommendations to the Pipeline and Hazardous Materials Safety Administration, the Dixie Pipeline Company, the American Petroleum Institute, and the Clarke County Board of Supervisors are included in the report.

Factual Information

Accident Synopsis

On November 1, 2007, at 10:35:02 a.m.¹ central daylight time,² a 12-inch-diameter pipeline segment operated by Dixie Pipeline Company (Dixie) was transporting liquid propane at about 1,405 pounds per square inch, gauge (psig), when it ruptured in a rural area near Carmichael, Mississippi. The resulting gas cloud expanded over nearby homes and ignited, creating a large fireball that was heard and seen from miles away. About 10,253 barrels (430,626 gallons) of propane were released. As a result of the ensuing fire, two people were killed and seven people sustained minor injuries. Four houses were destroyed, and several others were damaged. About 71.4 acres of grassland and woodland were burned. Dixie reported that property damages resulting from the accident, including the loss of product, were \$3,377,247.

Accident Narrative

At 10:35:02 a.m. central daylight time, Dixie's 12-inch-diameter propane pipeline segment ruptured about 2,650 feet downstream of Carmichael Pump Station near Carmichael, Mississippi. The map in figure 1 shows the route of the entire pipeline—from Mont Belvieu, Texas, to Apex, North Carolina—which comprises various sizes of pipe from several pipe manufacturers. The 12-inch-diameter pipeline segment starts on the west side of the Mississippi River near Erwinville, Louisiana, and continues eastward about 395 miles to Opelika, Alabama. Yellow Creek Pump Station is 19.28 miles upstream of Carmichael Station. The first pump station downstream of Carmichael is Butler Station, which is 18.3 miles east of Carmichael.

¹ The times associated with events indicated in hours:minutes:seconds are from either the Supervisory Control and Data Acquisition (SCADA) system or the 911 system.

² All times in this report are central daylight time except where otherwise noted.

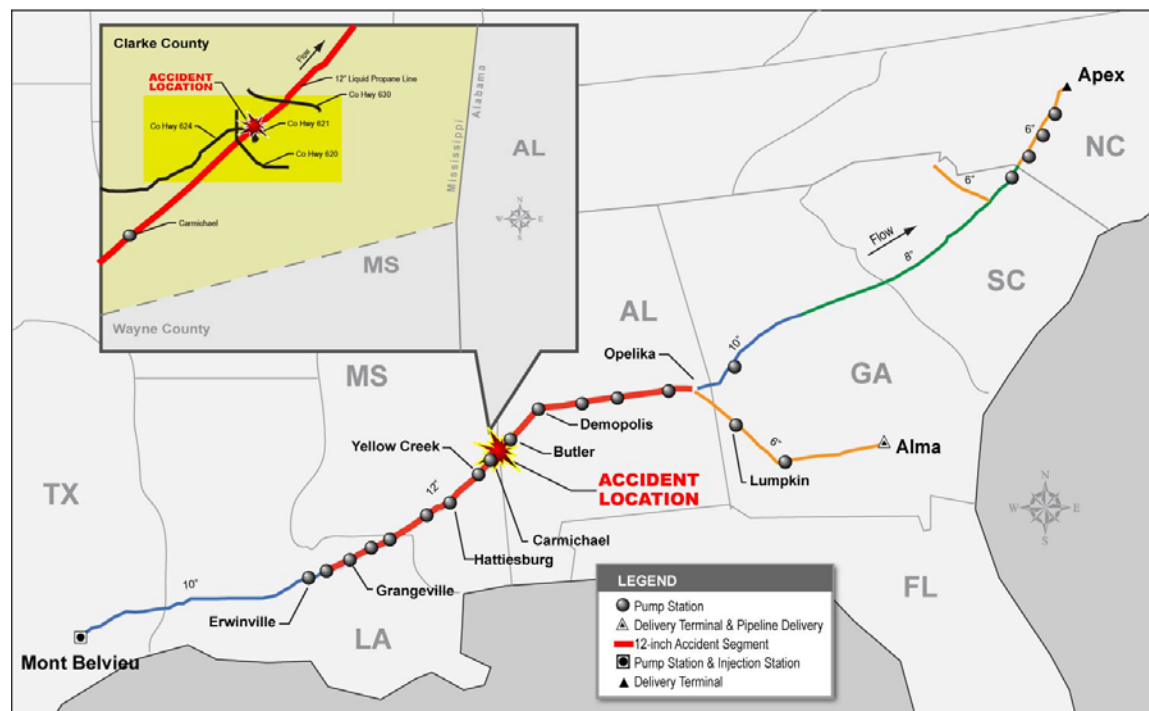


Figure 1. Map of Dixie pipeline.

The Dixie pipeline is owned by Enterprise Products Operating (Enterprise); the controller for the accident pipeline was located at Enterprise’s liquid pipeline Supervisory Control and Data Acquisition (SCADA) Control Center in Houston, Texas. The first indication of a problem was when the SCADA control panel displayed sequential discharge pressure measurements that indicated a large change in pressure at Carmichael Pump Station. At 10:35:07 a.m., the display showed a discharge pressure of 1,079 psig; at 10:35:13 a.m., the discharge pressure was 154 psig, indicating a large, sudden drop in pipeline pressure. Additionally, the display showed that Carmichael Station’s unit 2 pump had shut down because of low suction pressure. At 10:35:46 a.m., the SCADA display indicated that the rate-of-change in pressure at Butler Station, the next station downstream from Carmichael, was starting to decrease. Also, at 10:35:50 a.m., the SCADA display indicated that the rate-of-change in pressure at Yellow Creek Station, the first station upstream of Carmichael Station, was starting to come down.

When the pipeline ruptured at 10:35:02 a.m., liquid propane was released and instantaneously began to vaporize and form a low-lying propane gas cloud over the area. The propane gas did not ignite immediately; it ignited about 7 1/2 minutes later, at 10:42:30 a.m. Witnesses miles away reported seeing and hearing a large fireball and heavy black smoke over the area. The fire extended about 950 feet southwest and about 1,250 feet south of the rupture site. (See figure 2.) The fire fueled by the residual propane gas escaping from the pipeline

continued to burn at the ruptured pipe joint³ until the following day, when the fire at the pipe extinguished itself after flow control valves on both sides of the rupture were closed.



Figure 2. Aerial view of fire from pipeline rupture showing nearby destroyed houses.

At the time of the rupture, the flow of propane had increased from 5,952 barrels per hour to 7,354 barrels per hour. At 10:36:25 a.m., a little more than 1 minute after the SCADA display of the sudden pressure reduction, the controller decided that there was a leak in the Carmichael Station area, and he began shutting down the pipeline to reduce the amount of product released. At 10:37:12 a.m., the controller started the unit 1 pump at Butler Station (downstream of the rupture) to pull product away from the rupture area. About 10:38 a.m., the controller started calling field personnel from Hattiesburg and Demopolis Pump Stations to respond to the release.

About 10:41 a.m., a person in a house in the 8500 block of County Road 630 called the toll-free emergency number for Dixie to report an explosion and smoke near her house. Dixie's SCADA controller on duty recognized this report as indicating a product release from a pipeline in the Carmichael area.

At 10:46 a.m., the Dixie pipeline controller in Houston received a telephone call in which the caller described four explosions, fire 200 feet in the air, and two columns of white and black smoke. The caller said these were in "the area where a crude oil pipeline owned by Hunt [Crude]

³ A joint is a single length of pipe; the accident joint was about 52 feet long.

Oil [Supply Company] (Hunt) crosses the Dixie pipeline.” The controller then directed a contractor in the Carmichael area to go to the site. At 10:48 a.m., a Hunt employee told the controller that the Hunt pipeline had been shut down and blocked off in the area of the release.

At 10:49:51 a.m., the Dixie pipeline controller telephoned Clarke County Central Dispatch to provide notification of a pipeline leak in the Carmichael Station area. The controller was told that Clarke County officials were already aware of an event near that location and had dispatched trucks to the scene from several fire departments. The controller continued to isolate the rupture site by issuing commands through SCADA to close the remotely controlled block valves at the Butler and Carmichael Stations starting at 10:52:37 a.m. By 12:36 p.m., field technicians had closed the nearest manually controlled block valves, thereby completing the shutdown and isolation of the leaking section of the pipeline.

Weather conditions at the National Weather Service station in Meridian, Mississippi, around the time of the accident were reported as a clear sky (that is, no precipitation), a surface visibility of 10 miles, wind from the north-northeast about 7 mph with no significant wind gusts, and a ground level atmospheric temperature of 69° F. Sunrise was at 6:37 a.m. and sunset at 4:49 p.m.

Emergency Response

The first call received at Clarke County Central Dispatch, which operates the county’s 911 emergency call center, came in at 10:39:56 a.m. Two operators were on duty at the time. The call was from a person calling from a house at 4195 County Road 621. The caller reported that a gas explosion had occurred somewhere around the area and that smoke and gas surrounded the house. When asked if there was fire, the caller said that she did not see any fire but she saw white gas and smelled gas. The 911 operator told the caller that an emergency responder would be sent. The operator did not tell the caller to get out of the house and run away from the smoke. The call lasted 1 minute 20 seconds. The house at this address was subsequently identified as the house in which one of the two fatalities was discovered. At 10:40:13 a.m., during the first 911 call, the second 911 operator received a telephone call from a caller in a house in the 4300 block of County Road 621, about 600 feet south of the house where the first 911 call had originated. The caller reported that an explosion had occurred and he could see smoke when he walked out to the road. The call lasted 1 minute 33 seconds and concluded at 10:41:46 a.m. Clarke County Central Dispatch subsequently received numerous additional calls reporting the incident.

About 10:42 a.m., after receiving the first two 911 calls, Clarke County Central Dispatch placed a radio dispatch page to the Carmichael Volunteer Fire Department (CVFD) to respond to the house at 4195 County Road 621. The Clarke County Central Dispatch operating personnel did not know at that time that their fire department radio signal repeater⁴ did not transmit the page to the CVFD. Later, it was determined that the repeater system did not send a signal because it had been disabled during routine cleaning in the Clarke County Central Dispatch facility when a floor mop had accidentally dislodged the connector fittings of several communication cables about 90 minutes before the accident.

The assistant chief of the CVFD was at work about 1/4 mile from the CVFD fire station when, about 10:43 a.m., he heard the sound of a distant explosion. According to the assistant chief, the sound was followed shortly thereafter by the sound of a second explosion and perhaps the sound of a third explosion. About 10 to 15 seconds later, he saw a large plume and a cloud of heavy black smoke rising above the trees. The assistant chief immediately began mobilizing CVFD fire apparatus and personnel to the scene.

At 10:42:50 a.m., a caller at a construction site on a road north of Waynesboro, used a cellular telephone to call Wayne County, Mississippi, 911. The caller reported that an explosion had occurred northeast of his location. In a postaccident interview, this caller indicated that he had placed the 911 call about 20 seconds after he heard the sound of what appeared to be an explosion that occurred in the distance and after he saw a large plume and a cloud of heavy black smoke rising above the trees and moving northeast from his location. Following another 911 call that was received about 17 seconds after the 10:42:50 phone call, Wayne County 911 sent a Wayne County deputy sheriff to verify the incident location, and then, under a mutual aid agreement with Clarke County, dispatched Wayne County fire and rescue units to the scene.

About 10:44 a.m., because Clarke County Central Dispatch had not received a response from the CVFD acknowledging the page that had been placed about 2 minutes earlier, Clarke County Central Dispatch sent a second page, this time to the Theadville Volunteer Fire Department to respond to 4195 County Road 621.⁵ Clarke County Central Dispatch was still unaware at that time that the radio signal repeater was not functioning and the page to the Theadville fire department also had not been transmitted.

The Clarke County sheriff was at his residence about 20 miles from the accident site when about 10:44 a.m. he received a telephone call from Clarke County Central Dispatch asking whether there were any pipelines near County Roads 630 and 621, because a 911 call had just reported an explosion in that area. The sheriff responded that there was a pipeline in the Carmichael area. During postaccident interviews, the sheriff stated that he had been casually listening to his service radio just before this phone call, and there had not been any radio traffic

⁴ A *radio signal repeater* is a combination of a radio receiver and a radio transmitter that receives a radio signal and retransmits it at a higher level or higher power to relay radio signals across a wider area.

⁵ In accordance with Clarke County Central Dispatch operations protocol, a page is to be acknowledged by the department receiving the page. If no acknowledgement is received within about 2 minutes, the next closest fire department is paged and directed to respond. Clarke County Central Dispatch is to continue to page and dispatch a sequence of fire departments until an acknowledgement is received.

about an incident occurring in the Carmichael area. Clarke County Central Dispatch told the sheriff that two units (deputies) had been dispatched to that location and the CVFD had been paged to respond. The sheriff then told Clarke County Central Dispatch that he would monitor the radio closely for updates.

About 10:48 a.m., Clarke County Central Dispatch had not received a response from the Theadville Volunteer Fire Department acknowledging the page that had been placed about 4 minutes earlier. Clarke County Central Dispatch then repeated the page, this time to the Theadville, Quitman, and Carmichael Volunteer Fire Departments and the Desoto Fire Department.

About 10:55 a.m., the Clarke County Central Dispatch dispatcher had not received any responses acknowledging his pages to the four fire departments, and he began to suspect that the fire department radio signal repeater was not working and that none of the pages to the fire departments had been transmitted or received. Therefore, following the Clarke County Central Dispatch backup communication plan, the dispatcher switched to the Clarke County Sheriff's Department radio signal repeater, which was operating correctly.⁶

Concurrently, the Clarke County sheriff continued monitoring his service radio and did not hear any responses to the Clarke County Central Dispatch pages. The sheriff suspected that the fire department radio signal repeater had failed to transmit, but he was unable to contact Clarke County Central Dispatch because of the range limitations of his service radio. Accordingly, about 10:55 a.m., he contacted a deputy who was within transmission range and directed the deputy to notify Clarke County Central Dispatch that the radio signal repeater appeared not to be working and to use the Clarke County Sheriff's Department radio signal repeater to establish radio communications with the fire and rescue agencies. The sheriff then drove his personal vehicle to the site.

Accident Site

The pipeline rupture occurred in a cattle pasture in a relatively unpopulated area in Carmichael, Mississippi, which is an unincorporated section of Clarke County. The site was occupied by livestock at the time of the rupture. Clarke County has a population of 21,979 and an area of about 416 square miles. The accident site is about 12 miles southeast of Quitman, the Clarke County seat, about 3 miles north of the Wayne County line, and about 3 1/2 miles west of the Alabama-Mississippi state line. (See figure 1.)

About 200 residents live within a 1-mile radius of the accident site. The pipeline right-of-way in this area is oriented generally southwest-northeast. The ground rises slightly to the east and west of the rupture site, such that the rupture site is located at the base of a shallow valley. The pipeline is flanked on both sides by uncultivated fields and wooded lots. A 100-foot-wide

⁶ The Clarke County Fire Department and the Clarke County Sheriff Department can transmit and receive on each other's radio signal frequency.

zone in the middle of the right-of-way had been cleared of trees and shrubs. Federally required warning markers were located along the right-of-way to alert the public to the pipeline's presence and location, the product being transported, the identification of the owner/operator, and emergency contact information.

The buried Dixie pipeline crosses several feet above an 8-inch-diameter hazardous liquid (crude oil) pipeline operated by Hunt. The two pipelines cross about 170 feet east of the northeastern end of the ruptured pipe joint. Hunt representatives told National Transportation Safety Board (NTSB) investigators that the Hunt pipeline was neither involved with nor affected by the rupture of Dixie's liquid propane pipeline.

The Dixie pipeline passes beneath County Road 621 about 900 feet southwest of the ruptured pipe joint. A cluster of six houses is located about 500 feet southwest of the rupture site, with an additional cluster of five houses located a short distance farther south. All 11 houses are on County Road 621.

On-Scene Response

Upon hearing the explosion and seeing the fireball and heavy black smoke, at 10:43 a.m., the CVFD assistant chief drove his personal vehicle in the direction of the smoke to see the situation firsthand. While en route, the assistant chief spoke to the CVFD chief using his personal cell phone, which had a short-range wireless communication feature similar to a walkie-talkie. The two conferred briefly about what had occurred, made a preliminary identification of the location sufficient to direct CVFD resources to the general area of the accident, and agreed to mobilize the CVFD in response to the accident. The assistant chief then drove toward the CVFD fire station and used the short-range wireless feature on his cell phone to tell several other CVFD personnel what had occurred and to direct resources (two tanker trucks) to the scene.

A few moments later, the assistant chief and the CVFD captain arrived simultaneously at the CVFD fire station. They left immediately in a pumper truck and unsuccessfully attempted by radio to contact Clarke County Central Dispatch to report that they were en route to the scene. About 10:55 a.m. the assistant fire chief and the captain received word that the fire department radio signal repeater had apparently malfunctioned, and in accordance with the back-up communication plan, on-scene fire and rescue units were to switch to the Sheriff's Department radio frequency that used the sheriff's department radio signal repeater.

About 10:56 a.m., Clarke County Central Dispatch received a message from one of the on-scene deputy sheriffs reporting that the CVFD pumper truck with the CVFD assistant chief and the CVFD captain aboard, had just arrived at the scene at the intersection of County Roads 620 and 621, that the CVFD pumper truck was the first firefighting apparatus at the scene, that the CVFD had already begun to dispatch additional CVFD resources to the scene, and that the instruction to switch to the sheriff's department radio frequency had been received by the CVFD.

About 11:15 a.m., the Clarke County sheriff arrived at the intersection of County Roads 620 and 621, which later became the incident command post location. As prescribed by the Clarke County emergency management plan, the sheriff proceeded to implement an incident command process and assumed the role of incident commander. Later the incident command structure was elevated to a unified command system.

When the assistant fire chief and the fire captain approached the scene and saw a substantial fire and a cloud of heavy black smoke, they strongly suspected that the likely source of the fire was the propane pipeline buried underneath the cattle pasture. At the time, they did not know the extent of the fire and the number and locations of residents who might be endangered. Both recognized that the houses on County Road 621 would probably be in the greatest danger, so they drove the fire truck toward those houses.

The CVFD assistant chief stated during postaccident interviews that although he was aware that the pipeline transported highly flammable propane, the cause of what appeared to be a substantial rupture and product release and a fully involved fire, and the extent of damage to the rest of the pipeline, were not apparent to him at the time. Accordingly, the assistant chief drove the pumper truck on County Road 621 and stopped just short of the location where the Dixie pipeline passed beneath the road. The pumper truck was initially staged at that location, which became the initial forward command staging location. Additional fire and rescue units from other local fire departments were later staged at the parking lot of the Baptist church at the intersection of County Roads 630 and 632. Responding units from Alabama were staged on County Road 630 at the Alabama state line, and responding Wayne County resources were staged on County Road 620 at the Wayne County line.

When the assistant fire chief and the fire captain performed their initial assessment of the situation, they observed several civilians, whom they assumed to be residents of County Road 621 or 620, assisting others to leave the scene. Several sheriff's deputies arrived about that time, and they also began to assist civilians to leave the scene and to establish motor vehicle traffic control at the west end of County Road 621. A short distance to the east, CVFD personnel observed the burned remains of several houses and several other houses that were fully engulfed in flames and thus were deemed not salvageable. Fire had extensively charred the trees and grass in the area, but had essentially self-extinguished. Several small spot fires remained in the area, but they did not appear to present immediate danger to the evacuating civilians. In the open field, about 900 feet northeast of the initial staging location on County Road 621, there was a large, billowing, uncontrolled fire, which was believed by the CVFD to be within the linear boundary of the Dixie pipeline right-of-way. Flames extended into the air up to an estimated several hundred feet, and the heat generated could be felt as far away as 900 feet from the fire.

The two CVFD command officers were joined by the CVFD fire chief about 10:57 a.m. The CVFD chief assumed operational command of the responding fire and rescue resources. The CVFD fire chief and the assistant fire chief were aware that another pipeline traversed the open field in the vicinity of the fire; and, given the extent of heavy black smoke, it was unclear at first which pipeline was involved or whether both pipelines were involved.

The CVFD chief instructed the responding CVFD firefighters to search several residences in the immediate area and confirm that the occupants had been evacuated. Due to limited on-scene fire suppression resources at that time and the need to evacuate the area, fire suppression for the fully engulfed houses was deferred. The initial evacuation effort focused on houses and the one business located within about a 1/4-mile radius of the fire. A short time later, the evacuation radius was increased to about 1 mile. The CVFD conducted a brief inspection of what remained of the houses at 4195 and 4207 County Road 621, where the two fatalities were found (one at each location).

Upon completion of the initial civilian evacuation within a 1/4-mile radius, the CVFD began to put out the still burning fires in houses in the area. When those fires were out, about 12:00 p.m., the CVFD began to put out several small spot fires that remained in the wooded areas near the burned houses on County Road 621. These fires were suppressed by 2:00 p.m. Upon guidance from Dixie's *The Pipeline Group Emergency Response Manual* and the on-scene tactical response plan, the CVFD did not attempt to extinguish the ongoing fire at the ruptured pipeline. Accordingly, after the CVFD completed as much of the evacuation and fire suppression efforts that could be accomplished, it withdrew equipment and personnel to the intersection of County Roads 620 and 621 about 2:30 p.m.

Evacuations

After the propane gas cloud ignited, several residents of County Road 621 self-evacuated. The initial evacuation by the CVFD started about 11:00 a.m. on November 1 and was concluded about 7:20 p.m. for houses and one business that were not located in the immediate area surrounding the accident. For residences located on County Road 621 and the east side of County Road 620, the mandatory evacuation order was lifted at 10:00 a.m. on November 2.

Conclusion of On-Scene Response

On-scene activities continued until fire suppression and evacuation activities were fully concluded. A law enforcement presence at the site was deemed necessary only to provide security for the houses on County Road 621 that were damaged by the fire. The fire at the rupture site was officially declared extinguished about 5:05 p.m. on November 2, when the residual propane in the pipeline was exhausted. Incident command activities concluded on November 4 about 4:00 p.m. when on-scene activities ended.⁷

⁷ Several of the incident command staff remained at the relocated site for several days thereafter to continue to monitor the site and provide logistical support while pipeline removal and replacement activities continued.

Injuries

Two fatalities resulted from the fire, and seven people went on their own (not transported by ambulance) to hospitals or a medical center for emergency medical treatment. All of the injuries were minor, and all of the individuals were treated and subsequently released. No injuries to emergency responders or pipeline employees were reported. (See table 1.)

Table 1. Injuries.

Injuries ^a	Number
Fatal	2
Serious	0
Minor	7

^aTitle 49 *Code of Federal Regulations* 830.2 defines a fatal injury as: any injury that results in death within 30 days of the accident. A serious injury is defined as: an injury which requires hospitalization for more than 48 hours, commencing within 7 days from the date the injury was received; results in a fracture of any bone (except simple fractures of the fingers, toes, or nose); causes severe hemorrhages, nerve, muscle, or tendon damage; involves any internal organ; or involves second or third degree burns, or any burns affecting more than 5 percent of the body surface.

Damages

The fire destroyed four houses and caused structural damage to several others. The burned area encompassed an area of about 71.4 acres of grassland and woodland. Dixie reported that property damage resulting from the accident, including the loss of product, was \$3,377,247.

Postaccident Inspections

Pipeline

NTSB investigators and representatives of organizations participating in the investigation conducted a joint visual examination of the ruptured pipeline beginning about 11:00 a.m. on November 2. The ruptured segment of Dixie's 12-inch-diameter steel pipeline was visible in a narrow ditch. (See figure 3.) A longitudinal fracture of the pipe at about the 12 o'clock position was visible. At the rupture location the pipeline ran in a southwest to northeast direction, and the product flow was in the same direction. Flames about 3 to 5 feet high, resulting from residual fuel burnoff, were visible at the northeast end of the ruptured pipeline. Flames contained within the pipeline were also visible at the southwest end of the pipeline. A circumferential weld (girth weld) was visible at the upstream end of the fractured pipeline segment. The topsoil had covered a portion of the downstream end of the segment. In addition, some debris was present in the middle of the exposed pipeline segment.

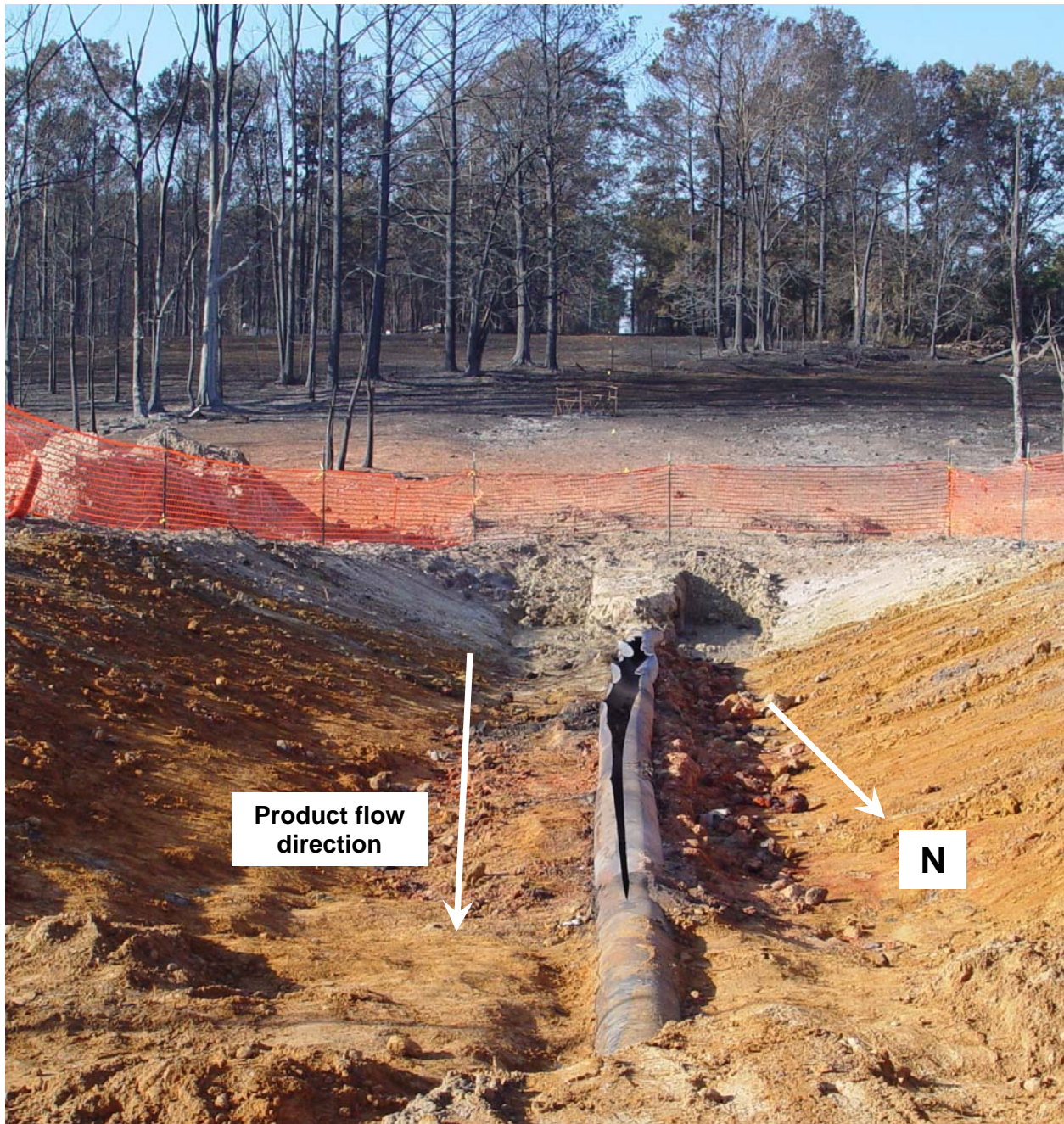


Figure 3. Ruptured pipe at Carmichael looking southwest. (Soil has been removed from around pipe to facilitate on-site examination.)

After it was safe for personnel to approach the pipeline, the ditch that contained the ruptured pipe was excavated by widening the ditch and reducing the steepness of its slope. During this excavation, the downstream end of the pipe joint was exposed. At the girth weld at the downstream end, the longitudinal fracture extended about 2 inches beyond the girth weld into the next pipe joint. The total fracture length and width at various locations along the fracture were measured. The widest separation, about 17 7/8 inches, was about 36 feet upstream from the

downstream girth weld of the ruptured pipe joint. Before the ruptured pipe joint was cut out and removed from the ditch, a surveying contractor measured the depth profile of the pipeline and estimated that the pipe joint had about 3 1/2 feet of cover for about 5 feet on either side of the trench at the time of the accident.

The on-site examination revealed no significant internal or external corrosion or fractographic features suggesting a potential location of fracture origin. As a result, about 72 feet of pipe that included the entire fractured joint and several feet of the pipe joints on both sides of the fractured joint were shipped to the NTSB Materials Laboratory for further evaluation. To facilitate shipment, the 72-foot-long section was divided into four smaller segments: two about 20 feet long and two about 16 feet long.

Surrounding Area

The grassland near the trench was burned, and the trees over a wide area displayed indications of fire damage. The Mississippi Forestry Commission estimated the area of fire-damaged woodlands and grasslands to be about 71.4 acres. About 40 head of cattle that were close to the accident site died as a direct result of the ignition of the propane gas cloud or were seriously injured and subsequently euthanized.

A cluster of six houses located on County Road 621 began about 512 feet southwest of the pipeline rupture site and extended west for about 500 feet. Two of the six houses were moderately damaged. The other four houses were fully consumed by fire. The two fatalities were found in and near, respectively, two of these houses.

A second cluster of five houses located on County Road 621 began about 600 feet further south of the first cluster of houses. Several of these houses also received fire and/or structural damage.

Pipeline Controller

The pipeline controller, who was operating the pipeline with the SCADA system at the time of the rupture, began his training in March 2006 and became a qualified controller in June 2006. The training completed by the controller was typical of that completed by other controller trainees at Dixie. The stages of training included learning the procedures, manuals, rules, and regulations governing the safe operation of the pipeline; on-the-job-training with a senior SCADA controller present; demonstration of competence in areas such as product flow, pressures, alarms, and valves; and simulator training.

Postaccident toxicology testing of the on-duty pipeline controller was performed and test results were negative for alcohol and illicit drugs.

Pipeline Information

The accident pipeline transported exclusively propane. Under the federal safety regulations for hazardous liquid pipelines codified in Title 49 *Code of Federal Regulations* (CFR) Part 195, propane is classified as a highly volatile liquid.⁸ The ruptured pipe joint was not located in a high consequence area.⁹

Design and Construction

The 395-mile-long 12-inch-diameter pipeline was constructed from American Petroleum Institute (API) grade X52 steel pipe that had a 12.75-inch outside diameter, and a 0.25-inch nominal wall thickness. Specifications for the grade X52 steel stipulate a minimum yield strength of 52,000 pounds per square inch (psi). Lone Star Steel Company (now owned by United States Steel Corporation) manufactured the pipe for Dixie in 1961 using a low-frequency electric resistance welding (ERW) process followed by a full-body normalizing treatment at a temperature of about 1,650° F. Individual pieces of pipe were joined together at the construction site using the shielded metal arc welding process. To prevent corrosion, the pipeline was field coated with coal tar enamel and felt wrap.¹⁰

The original 1961 pipeline construction documents contain welding specifications and procedures that included test welds; acceptance standards for the girth welds, all of which were to be subjected to radiographic inspection before installation; the repair or removal of defects; and a qualification test for welders. Although radiographic inspection was specified for field weld quality control during construction of the pipeline, Dixie did not find any documentation to indicate which girth welds were subjected to radiographic inspection. Also, no construction x-rays were found by Dixie.

Operating History

Records for the 2005 and 2006 annual external corrosion control surveys were reviewed. The company that performed annual cathodic protection surveys for Dixie found the system in good operating condition.

⁸ A highly volatile liquid is a hazardous liquid that will form a vapor cloud when released to the atmosphere and that has a vapor pressure exceeding 276 kPa (40 pounds per square inch [atmospheric pressure]) at 37.8° C (100° F).

⁹ *High consequence area* as defined in 49 CFR 195.450 means (1) a *commercially navigable waterway*, which means a waterway where a substantial likelihood of commercial navigation exists; (2) a *high population area*, which means an urbanized area, as defined and delineated by the Census Bureau, that contains 50,000 or more people and has a population density of at least 1,000 people per square mile; (3) an *other populated area*, which means a place, as defined and delineated by the Census Bureau, that contains a concentrated population, such as an incorporated or unincorporated city, town, village, or other designated residential or commercial area; or (4) an *unusually sensitive area*, as defined in 49 CFR 195.6.

¹⁰ *Coal tar enamel*, a pipeline coating, and *felt wrap*, a pipeline wrapping, often containing fiberglass, are external corrosion protection measures to isolate pipelines from environmental factors.

On November 1, 2007, the highest discharge pressure recorded at Carmichael Station was 1,417 psig, which was the pressure at the time of the rupture. The calculated pressure at the rupture site was about 1,405 psig at the time of the pipe failure. At the time of the accident, the calculated maximum operating pressure for the pipeline segment between Carmichael and Butler Stations was 1,448 psig.

The demand for propane is subject to seasonal variation, with the greatest demand in winter during heating season and the lowest during the summer months. During times of high demand, moving a greater volume of propane requires the pipeline to be operated at higher pressures. Pressure charts from Carmichael Station show that the most recent time period during which the pipeline at Carmichael had experienced operating pressures at or above 1,405 psig was from November 6, 2006, through February 23, 2007. On February 23, 2007, the last day the pressure was higher than 1,405 psig before the accident, the discharge pressure ranged between 562 and 1,435 psig; it was between 1,405 and 1,435 psig for about 5 hours 18 minutes.

Investigators reviewed aerial patrol¹¹ reports and pipeline contact reports since 2005, and they indicate no excavation activity in the area of the rupture. Dixie's *Report of Visual Inspection and Repair* forms also show that no work occurred at the rupture location.

Previous In-service Pipeline Failures

Before the accident, there had been no known leaks in the rupture area. However, for the entire 395-mile-long 12-inch-diameter pipeline, eight in-service releases had been reported to the U.S. Department of Transportation (DOT) before the Carmichael rupture. Four of the releases involved pump station piping. Of the remaining four releases, two were the result of third-party damage in Alabama, and two were the result of river floods in Louisiana. A non-reportable leak¹² caused by a 2-inch-long crack in a longitudinal seam weld occurred on September 2, 1984, in Alabama while the pipeline was operating at 1,440 psig. No in-service pipeline ruptures in girth welds have been reported for the entire pipeline.

¹¹ *Aerial patrol* refers to routine visual inspection of a pipeline from the air.

¹² Title 49 CFR 195.50 requires a leak of 5 gallons or more to be reported.

Preaccident Hydrostatic Pressure Tests

In October and November 1961, the entire 395-mile-long pipeline segment was hydrostatically pressure tested¹³ before it was placed in service. The test resulted in 13 pipe failures. Ten of the failures were characterized as seam splits or ruptures in the longitudinal ERW weld seams, and the remaining three included a pinhole leak in the seam weld, an undefined leak in the seam weld, and a leak from pipe laminations. The pipeline segment containing the accident pipe joint was successfully tested to 1,600 psig for a minimum of 4 hours on October 13, 1961.

Since the pipeline was installed, hydrostatic pressure tests that resulted in 60 longitudinal seam failures were conducted on segments of the 12-inch pipeline in 1983, 1984, 2001, 2002, 2004, 2006, and 2007 (May). (See table 2.) Dixie did not find any documentation that provided the reasons for the 1983 and 1984 hydrostatic pressure testing; however it was generally thought that these tests were conducted for maximum operating pressure validation as a result of new rules and guidance under 49 CFR Part 195. The hydrostatic pressure tests conducted from 2001 through May 2007 on the 12-inch pipeline served as baseline assessments or reassessments as required by the integrity management program. The pressure at which seams failed during these tests ranged from 1,670 to 2,006 psig.

Table 2. Dixie 12-inch Propane Pipeline's Preaccident Hydrostatic Pressure Retest Failure History.

Test Year	Segment	Failure Pressure Range (psi)	Failure Location
1983	Demopolis–Opelika	1,702–1,980	12 seam splits
1984	Hattiesburg–Carmichael	1,698–1,832	6 seam splits 1 weeping seam
	Carmichael–Demopolis	1,802–1,949	8 seam splits
2001	Mississippi River Trap–Grangeville	1,920	1 seam split
2002	Amite River–Grangeville–Hattiesburg	1,670–1,926	16 seam splits 1 seam seep leak
2004	Demopolis–Opelika (2nd retest)	1,900–2,006	8 seam splits
2006	Mississippi River Trap–Grangeville (2nd retest)	No Failures	None
2007	Amite River–Grangeville–Hattiesburg (2nd retest)	1,895–1,960	7 seam splits

¹³ In a *hydrostatic pressure test*, a pipe segment is filled with water at a specific pressure to test the strength and leak-resistance of the pipe.

In May 1984, Dixie conducted a hydrostatic pressure test on the pipeline segment between the Carmichael and Demopolis Stations, which included the accident pipe joint. During the test, eight seam splits occurred at pressures ranging from 1,802 to 1,949 psig. (See table 2.) The 1984 test was the only pressure test of the accident joint since it was installed in 1961.

Additionally, the 1984 hydrostatic test failures between Hattiesburg and Carmichael Stations included 6 seam splits and a seeping leak at a seam occurring between 1,698 and 1,832 psig.

Laboratory Examination of Previous Hydrostatic Pressure Test Failures. On February 17, 2006, Kiefner and Associates, an engineering contractor for Dixie, completed an analysis of the eight seam failures that occurred during the 2004 hydrostatic pressure test of the 12-inch-diameter low-frequency ERW pipe between Demopolis, Alabama, and Opelika.¹⁴ All of the seam failures were determined to be manufacturing defects including stitching,¹⁵ low ductility of the weld bond line, hook cracks,¹⁶ and cold welds.¹⁷ Seven of the eight failures had no obvious point of origin, and none showed any evidence of pressure-cycle-induced fatigue crack growth. The failure pressures on the 12-inch-diameter pipe were between 1,825 and 1,966 psig. Additionally, all eight failures occurred at stress levels exceeding 89.5 percent of the specified minimum yield stress of 2,039 psi.

On September 17, 2007, Stork Metallurgical Consultants (Stork), another Dixie contractor, prepared an analysis of the May 2007 hydrostatic pressure test from the Louisiana-Mississippi state line to Hattiesburg Station that included seven seam ruptures in the pipe. (See table 2.) The pipe failed at pressures between 1,895 psig and 1,960 psig. The contractor found no definitive features on the fracture surface to confirm the likely fracture origins. Three ruptures were attributed to hook cracks, three showed stitching, and one was at a weak and brittle weld that appeared to be a cold weld. Stitching was also evident in two of the ruptures with hook cracks.

In-Line Inspection Information

In May 1998, Tuboscope Vetco Pipeline Services inspected the pipeline segment from Hattiesburg, Mississippi, to Demopolis, Alabama, with a standard-resolution axial magnetic flux

¹⁴ *Final Report on Investigation of Hydrostatic Test Breaks that Occurred during the 2004 Hydrostatic Test of the Demopolis-to-Milner Segment of the Dixie Pipeline*, Kiefner and Associates, 2004.

¹⁵ *Stitching* is a variation in the properties of a weld from repetitive variation in welding heat. The variation creates a regular pattern of light and dark areas visible only when the weld is broken along the weld line. Stitching is associated with low-frequency ERW seams; the exposed fracture face exhibits faint repeated patterns that extend transversely through the wall thickness. (Information from *API Standard 5T*, 10th Edition, September 2003.)

¹⁶ A *hook crack* is a metal separation resulting from imperfections at the edge of a plate that are parallel to the surface and that turn to the inside diameter or outside diameter pipe surface when the edges are upset during welding. (Information from *API Standard 5T*.)

¹⁷ A *cold weld* is a metallurgically inexact term generally indicating a lack of adequate bonding strength of the abutting edges due to insufficient heat or pressure. A cold weld may or may not have a separation in the weld line. (Information from *API Standard 5T*.)

leakage metal loss tool for evidence of metal loss caused by internal corrosion. The test did not find any anomalies related to metal loss in the pipe joint that ruptured in this accident.

Before Enterprise Products LLC took over, Conoco Phillips was responsible for management of Dixie until 2005. On March 28, 2002, the managing partner of Dixie—Phillips Pipe Line Company—developed the initial integrity management program for Dixie. The initial baseline assessment completed under the integrity management program determined that a special ERW seam integrity assessment was needed for the Hattiesburg-to-Demopolis pipeline segment. In 2005, Dixie conducted the special assessment using a transverse magnetic flux leakage in-line inspection.

Dixie conducted the special ERW seam integrity assessment in 2005 using the General Electric (GE) UltraScan crack detection tool, which is an in-line inspection tool. This crack detection tool has the capability to detect defects in the pipe in the longitudinal direction, including lack of fusion, undercuts, weld cracks, and hook cracks in the longitudinal seam welds of ERW pipe. The smallest anomaly detection limits for the tool are 0.039 inch (1 mm) for depth and 0.984 inch (25 mm) for length, with an 85-percent probability of detection. This tool is not designed to detect defects in the girth welds.

The in-line inspection with the GE crack detection tool was conducted over the entire Hattiesburg-to-Demopolis segment in two separate runs from June 29 to July 1, 2005, and from August 2 to August 4, 2005. Two features were identified in the pipe joint that ruptured at Carmichael.¹⁸ The first was located 51 feet 5.2 inches downstream from the upstream girth weld. The feature was described as a 4.6-inch-long notch-like feature adjoining the seam weld whose depth was less than 12.5 percent of the wall thickness of the pipe.¹⁹ The second feature was located 51 feet 10.2 inches downstream from the upstream girth weld and was described as a geometry feature (that is, a deformation or a dent anomaly) 2.8 inches long and terminating 1.36 inches from the center of the downstream girth weld. Both features were reported in the pipe base metal close to the longitudinal weld seam. After the accident in Carmichael, GE reevaluated both features as adjoining the longitudinal seam weld.

In March 2006, Magpie Systems Inc. (Magpie) was hired by Dixie to inspect the Hattiesburg-to-Demopolis pipeline segment using a geometry tool to determine geometric anomalies (for example, dents and deformations) in the pipe, followed by a high-resolution axial magnetic flux leakage metal loss tool. A high-resolution magnetic flux tool like the one used by Magpie typically can detect metal loss in or near a girth weld at an 80 percent confidence level if the depth of the metal loss is 10 percent or more of the wall thickness of the pipe. Magpie reported no geometric anomalies and detected no metal-loss-related anomalies in the joint that ruptured in Carmichael.

¹⁸ For this inspection of the 120.7-mile pipeline segment, GE reported 14,357 features.

¹⁹ Although 12.5 percent of the wall thickness (0.031 inch) is less than the 0.039-inch detection limit of the tool, it is large enough to be detected with a reasonable degree of confidence (less than 85 percent).

Laboratory Examination of Pipe Removed After 2005 In-line Inspection. Based on the data from the 2005 in-line inspection of the Hattiesburg-to-Demopolis pipeline segment with the GE crack detection tool, GE identified 21 pipe joints of the 12-inch-diameter pipe with reportable indications. Dixie subsequently removed the 21 pipe joints, including the girth welds on each end of each joint, as part of its pipeline integrity repair program.

Dixie contracted with Stork to conduct hydrostatic pressure burst tests on the extracted joints and girth welds.²⁰ The pressures at which the 21 joints ruptured during the burst tests ranged from 2,055 psig to 3,250 psig. All of the pipe joint ruptures occurred above the specified minimum yield strength and along the longitudinal weld seam, although one also propagated partially along a girth weld. None of the fracture surfaces of the ruptured longitudinal weld seams exhibited any indications of fatigue crack growth.

For a majority of the 21 pipeline joints, Stork identified a general region or area of the fracture surface as the origin of the fracture. For each of these joints, either there was no definable fracture characteristic indicating the origin or an apparent fracture origin was not identifiable. For example, the fracture surface of one pipe joint had a chevron pattern²¹ that pointed to a general area of the fracture's origin, but no defect was observed to identify the exact location of the fracture initiation site. According to the Stork report, two joints had fracture surfaces with multiple flaws near the identified fracture origin region, and no hook cracks were found near the identified area of origin. The designated fracture origin sites for 11 of the pipe joints had hook cracks but did not have any definable fracture features, such as chevrons, pointing to an origin. Stork was unable to clearly identify an area of fracture origin for six pipe joints, even though hook cracks were present in the fracture surfaces of each joint. The fracture surface of only one pipe joint had a hook crack with chevrons found on each side pointing to the fracture initiation site.

Stork also correlated the location of the identified fracture origin for the pipe joints with indications reported from the 2005 in-line inspection by the GE crack detection tool. The report stated that for three of the pipe joints, the identified fracture origin coincided with an indication detected during the 2005 in-line inspection. The burst pressures for these three pipe joints were between 2,250 and 3,190 psig. Stork's report further stated that the in-line inspection had reported indications along the entire fracture surface for nine other pipe joints, and five other pipe joints had no reported indications from the in-line inspection along the entire fracture surface. For the remaining four pipe joints, Dixie reviewed the in-line inspection test data and confirmed that these four pipe joints also had no reported indications along their fracture surfaces from the in-line inspection.

²⁰ Stork submitted its draft report, *Testing and Examination of Pipe from Dixie Pipeline Company's 12-inch Hattiesburg, MS, to Demopolis, AL, Pipeline*, on March 30, 2007. The final report (No. 0270-07-17309), issued March 14, 2008, had no significant changes from the draft report.

²¹ A *chevron pattern*, also called a *herringbone pattern*, occurs on an overstress fracture surface and contains features that look like nested V's. The V's point in the direction opposite the direction of fracture propagation.

Stork also performed fatigue tests on sections cut from two of the ruptured pipe joints from the burst tests in which the fracture did not extend along the entire length of the pipe joint, thereby leaving sufficient undamaged pipe to create test sections. The two sections used for the fatigue tests were taken from separate pipe joints that failed during the burst tests at 2,250 psig (section 1) and at 3,025 psig (section 2). Each section contained a single girth weld. The two fatigue tests were conducted with pressure cycling between 300 psig and 1,440 psig.

Section 1 ruptured along the longitudinal weld seam after 1,768 cycles. The rupture was 3 feet 8 inches long and was in a region where no indications had been reported during the 2005 in-line inspection. Stork reported that the appearance of the fracture surface indicated that the failure started at a large hook crack with some bright fracture marks present that indicated likely fatigue crack propagation. Oxide scale was found along the surface of the hook crack, and Stork believed that this indicated that the scale originated during manufacture of the pipe. Smaller hook cracks were also present on the fracture surface. The fracture surface of section 1 had two regions that contained lack-of-fusion indications; the lack-of-fusion indications were 18 inches long with a depth of 34.4 percent of the wall thickness, and 24 inches long with a depth of 38 percent of the wall thickness, respectively.

Section 2 had indications of three cracks along the longitudinal seam from the 2005 in-line inspection. The data from the in-line inspection indicated that the longest crack was about 54 inches long with a depth of 36.8 percent of the wall thickness. Despite this large indication, Stork reported that section 2 failed to rupture after 92,636 pressure cycles, at which point the test was terminated.

Tests and Research

Metallurgical Examination of Accident Pipe

The rupture extended over a longitudinal distance of about 52 feet 4.75 inches. A major portion of the fracture extended through the longitudinal ERW seam. The downstream end of the fracture crossed a girth weld and continued about 1 inch into the body of the adjoining pipe joint. (See figure 4.) On the upstream side of the ruptured pipe joint, the fracture followed the downstream edge of the circumferential girth weld for about 1.8 inches. At this point it ran longitudinally across the girth weld and then progressed another 1.2 inches along the upstream edge of the girth weld. The fracture then continued along a curved trajectory for about 12 inches into the base metal of the upstream pipe joint, leaving an open flap of pipe at the upstream girth weld. (See figure 5.)

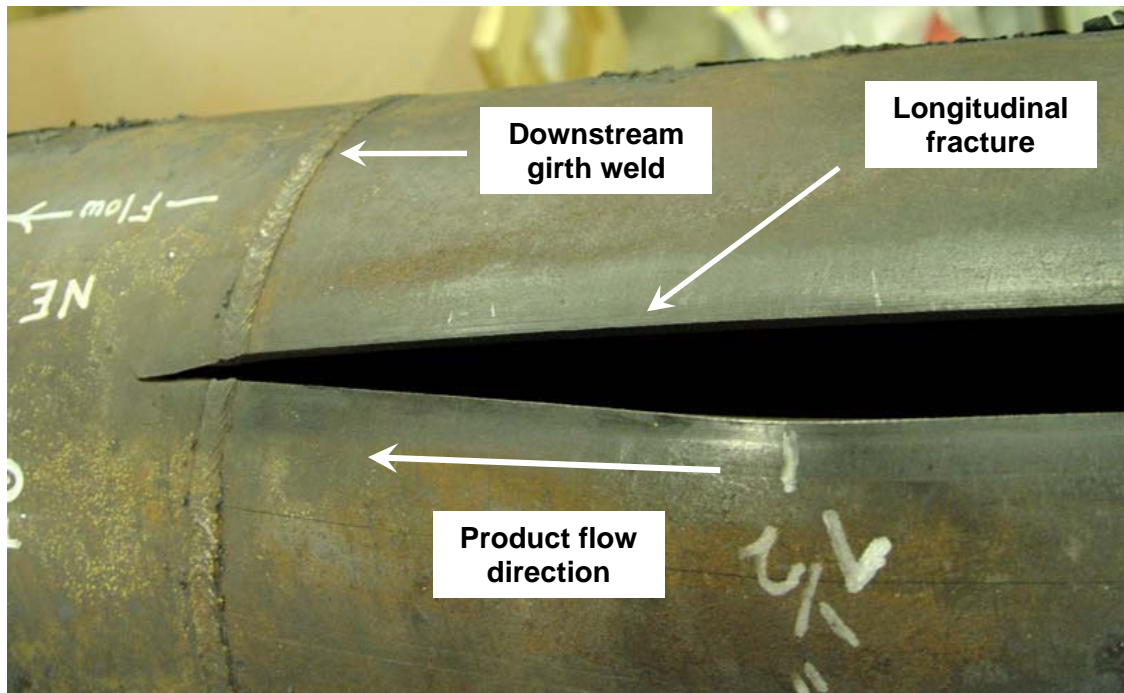


Figure 4. Downstream end of rupture.

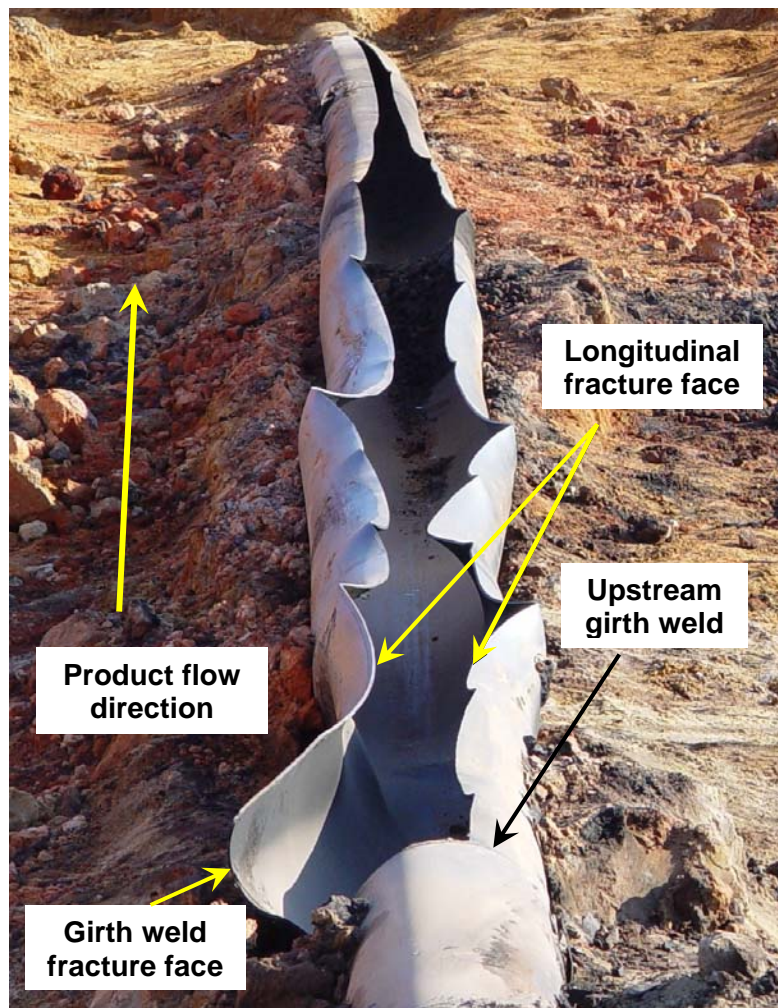


Figure 5. Ruptured pipe.

Fractographic examination²² of the entire fracture along the longitudinal seam and the upstream girth weld did not reveal a definitive point of fracture origin in the accident pipe, although the fracture faces along both welds had various features of interest that were thoroughly examined during the investigation.

The fracture faces along the seam weld were covered with a layer of oxide that is consistent with exposure to fire. The fracture faces of the seam weld between the center and upstream end of the ruptured pipe joint had regions containing what appeared to be smooth island-like²³ features. In this area the fracture followed the upturned grains that resulted from the ERW process. The island-like features appeared as projections surrounded by a fracture with a rougher texture. In cross-section, the island-like features looked like the letter “J;” they followed

²² A *fractographic examination* looks at the characteristics of a fracture surface to determine the direction of crack propagation and the fracture mechanisms.

²³ An island feature has a flat top with cliff-like sides above the flat fracture face. On the mating fracture face, the island-like feature extends below the flat fracture face.

a fracture path similar to a hook crack. Inspection of the longitudinal weld seam fracture faces also showed faint repeated patterns that extended transversely across the wall in many areas consistent with features called stitching in ERW seam welds.

Examination of the fracture faces of the longitudinal ERW seam fracture revealed chevron pattern fragments in areas located about 2.5 inches and 4 inches downstream from the upstream girth weld. (See figure 6.) The orientation of the chevron patterns indicated that the fracture was propagating in the upstream direction, along the longitudinal seam weld toward the girth weld. The longitudinal ERW seam fracture and the upstream girth weld fracture intersected at about a right angle. At the transition between the fractures was a branching crack, which also indicates fracture propagation in the upstream direction, toward the girth weld.

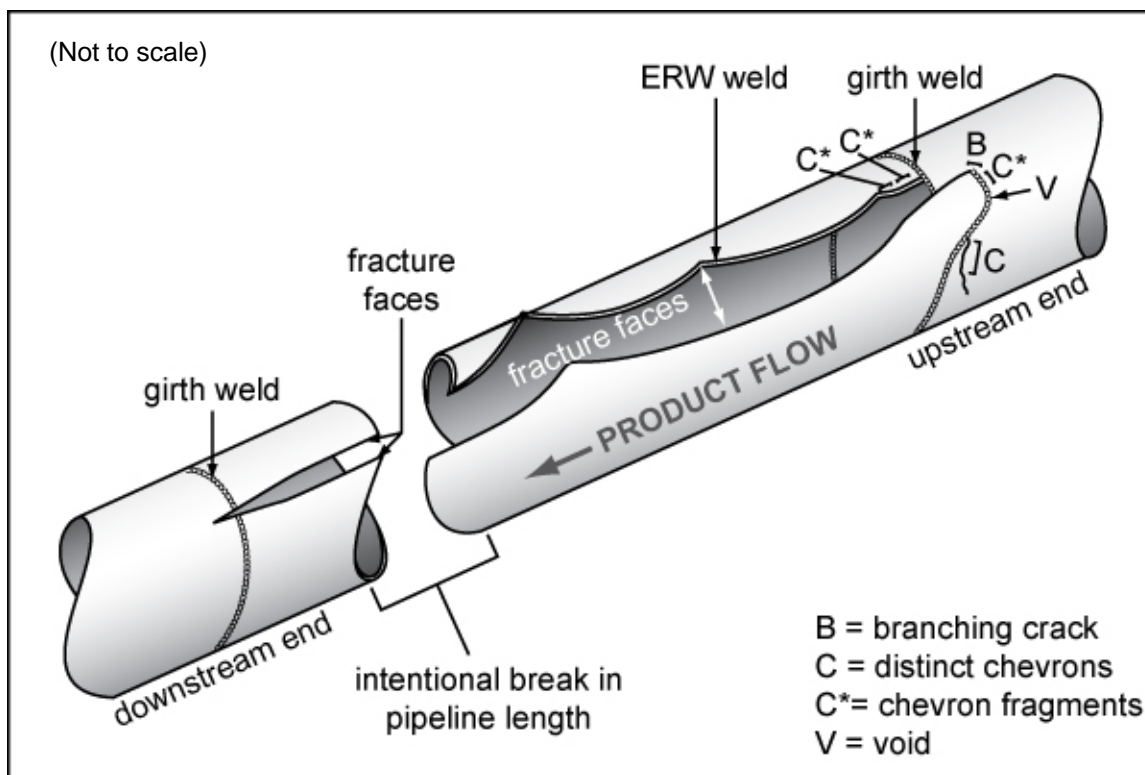


Figure 6. Schematic drawing of accident pipe identifying welds and showing fracture features of interest.

Fractographic examination of the girth weld showed no evidence of a preexisting crack (such as radial or crack arrest marks that originate from a specific location). Examination of the downstream face of the girth weld fracture revealed that a 1-inch fracture portion adjacent to the ERW seam fracture contained faint chevron fragments indicating that the fracture was propagating away from the seam. A void²⁴ found in the upstream girth weld was about 0.05 inches in cross section at the fracture surface. Welding standards in effect both at the time

²⁴ A void in a metal is any discontinuity manifested by a lack of material by pullout or other conditions. A pore in a metal is a cavity discontinuity formed by shrinkage or gas entrapment during solidification.

of pipeline construction and currently permit a pore that is the smaller of 25 percent of the pipe wall thickness or 0.0625 inch. Accordingly, the void in the accident pipe as measured along the plane of the fracture surface would have been within the permissible size.

The fractured wall (base metal) of the upstream pipe joint adjacent to the upstream girth weld had a distinct chevron pattern between 2.5 inches and 7.5 inches from the intersection of the longitudinal weld seam and the upstream girth weld. The orientation of the chevrons shows that in this region the crack propagated away from the ruptured welds.

Transverse Charpy V-notch²⁵ impact tests were also conducted on specimens from the pipe wall (base metal) and the ERW seam of the pipe joint downstream from the accident pipe joint to compare the toughness of the base metal in the pipe wall to that of the metal in the seam weld. The results of the Charpy tests showed that the average impact value for the ERW seam was about 44 percent lower than that of base metal.

Two nearly parallel scratch marks were observed on the outside surface of the accident pipe about 37 feet 10 inches upstream from the downstream girth weld and about 2.5 inches from the ERW seam. No significant inward denting of the pipe wall was observed near the scratch marks. There also was no evidence of general corrosion damage, V-groove corrosion²⁶ along the longitudinal weld seam, or indications of stress corrosion cracking.

Finite Element Analysis

Because of the unique shape of the ruptured pipe in the vicinity of the upstream girth weld fracture, a series of finite element analyses were performed to simulate the deformation of the pipe for various fracture initiation sites and fracture propagation sequences. The following specific deformation characteristics were used as benchmarks to evaluate the simulations:

- The 5-inch (45-degree) segment of the girth weld fracture adjoining the seam weld fracture had its radius reduced from about 6 inches to about 4 inches. The remainder of the circumferential fracture was flat rather than curved.
- The pipe flap surface in the region of the seam fracture sloped down toward the original pipe location for about 1 1/2 feet from the girth weld fracture in the downstream direction.

²⁵ Charpy V-notch impact testing is a method for determining the dynamic toughness of a material. In Charpy testing, a falling pendulum strikes a rectangular specimen that has a V-shaped notch in the middle and is supported at each end. The test measures the amount of impact energy (typically in foot-pounds) that is required to fracture a specimen. In a transverse Charpy V-notch specimen, the width of the notch is aligned parallel to the longitudinal direction of the pipe.

²⁶ V-groove corrosion is localized crevice corrosion that intersects the longitudinal weld seam and forms an external deep, narrow crack-like groove.

- On the side of the pipe that did not have a girth weld fracture, the pipe wall showed almost zero deformation for about 2 feet in the downstream direction from the upstream girth weld.

More than 60 simulations were performed covering a wide range of fracture initiation and propagation scenarios and pressure decay spatial distributions. The simulation results were first classified by their correlation to the three deformation benchmarks.

For fracture initiation in the seam weld, two series of simulations were performed. The first series assumed that a crack initiated far downstream from the upstream girth weld and propagated into the upstream region and then along the path of the circumferential fracture. The second series assumed that a crack initiated in the seam near the upstream girth weld and propagated in both directions. When the crack intersected the upstream girth weld, it transitioned to a circumferential fracture. No simulation for either of these scenarios predicted deformation characteristics consistent with the three benchmarks.

For fracture initiation in the girth weld, a series of simulations were performed that assumed that a crack initiated somewhere along the girth weld, grew along the circumferential fracture path, and initiated a fracture along the seam weld when the crack and the seam weld intersected. All of these simulations were in general agreement with the three deformation benchmarks.

Another simulation was performed in which the fracture was assumed to initiate at the location of the void found along the girth weld fracture surface. When the predicted stress state for this fracture sequence was evaluated, it was noted that after the fracture had grown from the void and approached the seam weld, a region of high stress—centered about 1 inch downstream of the upstream girth weld—developed along the seam weld. The simulation was therefore rerun with the assumption that in this high-stress region, another fracture initiated in the seam weld. This fracture sequence resulted in the best agreement with the deformation benchmarks in shape and correlated very well with the accident pipe in magnitude of deformation.

A very specific type of stress distribution is required to create the distinct chevron pattern that was observed on the circumferential fracture where it transitioned into the upstream pipe joint. Examination of the predicted stresses at this stage of the fracture sequence showed that most of the girth weld initiation sequences were consistent with chevron development. None of the seam weld initiation simulations predicted stress states consistent with chevron development in the upstream pipe joint.

ERW Pipeline

Early (pre-1970) ERW processes used low-frequency alternating current (30 to 60 hertz) to produce welding heat. Since 1970, ERW pipe has been produced using high-frequency alternating current (350 to 500 kilohertz).²⁷ Based on the 2007 hazardous liquid pipeline annual reports submitted by the pipeline operators to the Pipeline and Hazardous Materials Administration (PHMSA), there were 47,772 miles of low-frequency ERW pipe in liquid pipeline service, including 12,058 miles that transport highly volatile liquids. Additionally, there were about 68,021 miles of high-frequency ERW pipe in liquid pipeline service, including 33,337 miles that transport highly volatile liquids. Together, low- and high-frequency ERW pipe account for 115,793 miles, or about 68 percent of the 170,069 miles of hazardous liquid pipelines in service in 2007.

Performance of Low-Frequency ERW Pipe

During discussions with NTSB staff, PHMSA has stated that low-frequency ERW pipe manufactured before 1970 has presented more fracture problems than pipe constructed with any other method, and that the pre-1970s-era low-frequency ERW pipe has a much higher failure rate than newer ERW pipe. PHMSA attributed these performance problems to the quality of available steels and problems associated with the welding process. According to PHMSA, over the years, steel production processes evolved with better quality controls, which led to the production of steels with improved properties like higher yield strengths, increased toughness, and improved weldability. By the 1970s, the low-frequency ERW process was superseded by the high-frequency ERW process, resulting in the improvement of both seam weld quality and the production rate of ERW pipe. PHMSA representatives further noted that for ERW seam ruptures, identification of a definitive fracture origin is not possible about 50 percent of the time, and that usually only a region in which the fracture originated can be identified.

In August 1989, PHMSA²⁸ released Technical Report OPS 89-11, *Electric Resistance Weld Pipe Failures on Hazardous Liquid and Gas Transmission Pipelines*. According to the report, for in-service failures between 1977 and 1988 in low-frequency ERW hazardous liquid pipelines for which metallurgical reports were available, lack-of-fusion defects accounted for 23 percent of the failures, selective corrosion for 23 percent of the failures, and fatigue/corrosion fatigue for 31 percent of the failures. Hook cracks accounted for 15 percent of the failures.

PHMSA data from 2002 through 2007 indicate that 12 reported pipeline incidents (8 seam ruptures and 4 seam leaks) involved low-frequency ERW seams and 7 incidents (5 seam ruptures and 2 seam leaks) involved high-frequency ERW seams. PHMSA data state that during the same period, there were eight girth weld incidents; all involved leaks with no catastrophic ruptures. According to PHMSA, although ERW pipe seam failures are infrequent, they tend to be

²⁷ *Integrity of Vintage Pipelines*, Interstate Natural Gas Association of America, 2004.

²⁸ In a DOT reorganization, the Research and Special Programs Administration (RSPA) ceased operations on February 20, 2005. RSPA's Office of Pipeline Safety programs moved to the new Pipeline and Hazardous Materials Safety Administration. All references to predecessor agencies are designated as PHMSA in this report.

catastrophic, and about 98 percent of all ERW pipe failures involve the seam weld. Historically, girth weld failures that have been reported usually involved soil movement. Both on-scene and subsequent examinations found no evidence of soil pipe movement.

PHMSA also stated that because more pressure cycling results in greater fatigue, the high numbers of pressure cycles in older low-frequency ERW pipelines has to be considered when determining pipeline longevity. PHMSA is looking at ways for operators to minimize pressure cycling and characterized Dixie's pipeline pressure cycling as higher than average. However, because pipe performance varies depending on many factors, PHMSA felt that there is no uniform pressure cycling standard that can be applied to all pipeline operators when calculating flaw growth rates.

Federal Oversight and Studies

In 1988 and 1989, PHMSA issued two Alert Notices to all natural gas transmission operators and all hazardous liquid pipeline operators who had ERW pipe manufactured before 1970. In the first notice (ALN-88-01, issued January 28, 1988), PHMSA recommended that

all operators reevaluate the potential for safety problems on their high-pressure pre-1970 ERW pipelines. All operators who have pre-1970 ERW pipe in their systems should carefully review their leak, failure, and test history as well as their corrosion control records to ensure that adequate cathodic protection has been and is now being provided. In areas where cathodic protection has been deficient for a period or periods of time, the operators should conduct an examination of the condition of the pipeline, including close interval pipe-to-soil corrosion surveys, selective visual examination of the pipe coating, and/or other appropriate means of physically determining the effects of the environment on the pipe seam. If an unsatisfactory condition is found, or if a pre-1970 ERW pipeline has not been hydrostatically tested to 125 percent of the maximum allowable pressure, operators should consider hydrostatic testing to assure the integrity of the pipeline.

In the second notice (ALN-89-01, issued March 8, 1989) PHMSA stated the following:

[PHMSA] is planning to conduct research aimed at characterizing ERW defects and their growth rates for a variety of environmental conditions, in addition to the pipe having cathodic protection at less than standard pipe-to-soil potentials, coating disbondment, fatigue, and corrosion fatigue. If the research is successful, the resulting data could provide a basis for establishing criteria regarding when an ERW pipeline should be re-hydrotested.

The notice included the following recommendations:

- (1) Consider hydrostatic testing on all hazardous liquid pipelines that have not been hydrostatically tested to 125 percent of the maximum allowable pressure, or alternatively reduce the operating pressure 20 percent;
- (2) Avoid increasing a pipeline's long-standing operating pressure;
- (3) Assure the effectiveness of the cathodic protection system. Consider the use of close interval pipe-to-soil surveys after evaluating the pipe coating and corrosion/cathodic protection history; and
- (4) In the event of an ERW seam failure, conduct metallurgical examinations in order to determine the probable condition of the remainder of the ERW seams in the pipeline.

In May 1994, 49 CFR Part 195 was amended to include pressure testing requirements for older hazardous liquid and carbon dioxide pipelines. The amendment required that operators not transport a hazardous liquid in a steel interstate pipeline constructed before January 8, 1971, a steel interstate offshore gathering line constructed before August 1, 1977, or a steel intrastate pipeline constructed before October 21, 1985, unless the pipeline had been hydrostatically pressure tested for at least 4 continuous hours at a pressure equal to 125 percent or more of the maximum operating pressure (and, in the case of a pipeline that was not visually inspected for leakage during the test, for at least an additional 4 continuous hours at a pressure equal to 110 percent or more of the maximum operating pressure) or the pipeline operated at 80 percent or less of a qualified prior test or operating pressure.

After an accident involving a pre-1970 low-frequency ERW pipeline, PHMSA usually requires the operator to reduce operating pressure and conduct spike tests. The spike test is a variation of a hydrostatic pressure test in which a higher hydrostatic pressure (typically 100 percent of specified minimum yield strength or 1.39 times the maximum allowable pressure) is applied for a short duration of time, typically less than 30 minutes. The spike test is intended to eliminate flaws that may otherwise grow to failure at normal operating pressures. In comparison to a normal hydrostatic pressure test, the spike test limits the time the line is at the higher pressure to reduce the potential amount of crack growth. To ensure long-term integrity, PHMSA requires the operators to establish a conservative reinspection interval based on the potential defect size, pipe characteristics, and cyclic operating pressure data. The actual inspection interval typically is half of the calculated interval to take unknowns into account. PHMSA believes that it has been fairly successful in making certain that flaw growth rate projections are conservatively calculated in order to determine the appropriate pipeline inspection frequency.

PHMSA advised that during every integrity management and other audit, it checks to see that each pipeline operator that uses low-frequency ERW pipe, flash welded pipe, or lap welded pipe (a process from the 1930s) has a plan that describes how the operator intends to mitigate

potential threats posed by the pipelines. The plan must be risk based and requires a baseline assessment and remedial measures. The results of pipeline tests are factored into the plan so that more aggressive assessments can be pursued when needed.

At PHMSA's June 24–25, 2009, public forum, topics for potential future research were discussed. One area for research for PHMSA's consideration was identification and understanding of failure mechanisms in ERW pipe.

Postaccident Actions

PHMSA

PHMSA issued a Corrective Action Order on November 2, 2007, requiring Dixie and its corporate owner, Enterprise, to immediately take the following corrective actions:

- Not operate the pipeline segment until authorized to do so by the director for PHMSA's southern region.
- Develop a return-to-service plan for the pipeline.
- Maintain a 20-percent pressure reduction along the entire 12-inch pipeline segment from Erwinville, Louisiana, to Opelika, Alabama.
- Hire a consultant to examine the in-line inspection surveys for the pipeline and tabulate the results.
- Submit a written plan and schedule to PHMSA for verifying the integrity of the entire pipeline segment. The plan must provide integrity testing that addresses all factors known or suspected in the failure, which may include, but not be limited to the following:
 - In-line inspection tool surveys and remedial action. The type of in-line inspection tools used shall be technologically appropriate for assessing the system based on the type of failure that occurred on November 1, 2007, with emphasis on identifying and evaluating the following: (1) anomalies associated with dents, grooves, and gouges; (2) metal loss due to corrosion; (3) the orientation of the longitudinal pipe seam; (4) pipe deformation; and, (5) longitudinal cracks, mill defects, and stress corrosion cracking.

- A detailed description of the inspection and repair criteria to be used in the field evaluation of the anomalies that are excavated. This includes a description of how many defects are to be graded and the schedule for repairs or replacement.

The corrective action order stated that Dixie or Enterprise could request approval from the director of PHMSA's southern region to increase the operating pressure above the interim maximum pressure when Dixie or Enterprise submitted an analysis demonstrating that the hazard had been abated or that a higher pressure was justified based on an analysis of all known defects, anomalies, and operating parameters of the pipeline segment.

On February 19, 2008, PHMSA issued a Notice of Probable Violation and Proposed Compliance Order to Dixie for failing to follow the procedures in 49 CFR 195.402 pertaining to the operator's procedure manual for operations, maintenance, and emergencies. The alleged violation was exceeding the design pressure for a component covered under 49 CFR 195.406, *Maximum Operating Pressure*. The compliance order required Dixie to review the data presented in the manual and then follow its procedures to establish maximum operating pressures meeting all requirements of Part 195.406. In response to the PHMSA notice, Dixie made changes to the manual, and on May 1, 2008, Dixie gave PHMSA an additional response on exceeding the design pressure for a component.

Dixie Pipeline

After the pipeline rupture, Dixie conducted a hydrostatic pressure test of a 12-mile segment of the 12-inch-diameter pipeline downstream of Carmichael Station on November 8, 2007. The test was required by PHMSA before Dixie was allowed to return the pipeline to service at a reduced operating pressure. During the higher stress portion of the hydrostatic pressure test (spike test), the pipe was pressurized to 1,979 psig at the hydrostatic test pressure recorder location at milepost 427.29, near Bucatuma Creek. This pressure was about 1.38 times the maximum operating pressure of 1,435 psig for Carmichael Station. About 6.71 miles downstream of Carmichael Station, a 10-foot 6-inch-long longitudinal seam weld rupture occurred in a pipe joint located about milepost 432.19. The calculated pressure at the rupture location was 1,915 psig.

The 10-foot 6-inch rupture was examined by the NTSB Materials Laboratory. This fracture also was in and adjacent to the longitudinal ERW seam. The fracture faces contained island-like features similar to those found on the accident pipe and that are associated with hook cracks. No fractographic features indicative of the origin of the fracture were observed. Isolated regions of the "J" fracture were covered with a thin, uniform layer of iron oxide scale that extended from the exterior surface to as much as 20 percent of the wall thickness.

After this hydrostatic pressure test, GE reviewed its data from the 2005 in-line inspection and confirmed that its data showed a crack-like feature 3.5 inches long with a depth of 25 to 40

percent of wall thickness.²⁹ The crack-like feature adjoined the ruptured seam weld, about 13 feet 7 inches downstream of the upstream girth weld. Additionally, Magpie reviewed its data from the 2006 in-line inspection and found that its inspection neither recorded nor detected any features on the ruptured pipe joint.

In August 2008, Dixie radiographed 68 girth welds from the 12-inch pipeline that were removed for various reasons and found 4 welds that would not have met current welding standards. Of those four welds, three had inadequate penetration of the root-weld pass and the fourth had a hole in the girth weld, caused by excessive heat during the welding process, that was later repaired. The three welds with inadequate penetration also would not have met the standards in place in 1961 at the time the pipeline was constructed.

Postaccident Emergency Response Debriefing

On November 4, NTSB staff conducted a debriefing after the on-scene fire and rescue response to the Carmichael accident had been concluded. The debriefing was attended by principals of the primary responding fire and rescue agency (CVFD), the primary responding law enforcement agency (Clarke County Sheriff's Department), the jurisdictional emergency management agency (Clarke County Emergency Management), Dixie and Enterprise pipeline personnel, and PHMSA.

The Clarke County sheriff, the Clarke County communications director, and a member of the County Board of Supervisors discussed the difficulties with the fire and rescue radio communication system that required the switch to the sheriff's department radio system. They stated that the Clarke County government had completed a hardware modification to help prevent future accidental disconnections of the communication cables and that since the accident the County conducts biweekly tests of the radio dispatch system. The County indicated that it would also improve coordination with the technical maintenance contractor of its radio communications equipment and enhance countywide communications.

Pipeline Operator Public Education Programs

Regulations and Standards

Under the Pipeline Safety Improvement Act of 2002, each pipeline operator was required to develop and implement a written, continuing public education program (including both awareness for the general public and training for and outreach to emergency response agencies), and the DOT was to issue standards prescribing the elements of an effective public education program. In response to these mandates, PHMSA issued a final rule on May 19, 2005, that

²⁹ Although this crack-like feature was detected by GE, the flaw was considered subcritical, with an estimated life of about 10 years. Therefore, the pipe joint was not recommended for immediate replacement.

required each operator of a gas or hazardous liquid pipeline to develop and implement a written, continuing public education program that follows the guidance provided in API Recommended Practice 1162 (API RP 1162), *Public Awareness Programs for Pipeline Operators*, which was also incorporated by reference in 49 CFR Parts 192 (gas transmission lines) and 195 (hazardous liquid pipelines) under this final rule. Operators in business on June 20, 2005, were to have completed their written programs not later than June 20, 2006. An operator's program documentation and evaluation results also had to be available for periodic review by appropriate regulatory agencies.

Following the publication of the new regulations, PHMSA established a process to review by the June 2006 deadline all public education plans and to identify those plans that did not meet the critical elements and that required revision. In response to the mandate for operators and PHMSA to evaluate the effectiveness of the public education programs, PHMSA stipulated that operators were to assess the effectiveness of their programs within 4 years, that is, by June 20, 2010.

Before the passage of the Pipeline Safety Improvement Act, the pipeline industry had developed recommended practices for public education programs. In 2001, at the request of PHMSA, the API developed a new standard, designated API RP 1162, for public education programs by hazardous liquid pipeline operators. In the preamble to the May 2005 final rule, PHMSA stated that "with the support of PHMSA, [the] API expanded the scope of the recommended practice to include gas transmission and distribution operators." A multi-industry task force, including representatives of hazardous liquid, gas transmission, and distribution pipeline operators, developed the expanded version of API RP 1162, resulting in the publication of the first (still current) edition in December 2003.

API RP 1162 contains specific guidance about the development of public awareness programs directed to the general public and training and outreach programs directed to emergency response agencies. API RP 1162 also defines stakeholder audience, includes information to be disseminated to the stakeholder audience, discusses message delivery methods and enhancements to a baseline public awareness program, and describes program documentation, record-keeping, and evaluation. Regarding training and outreach programs for emergency response agencies, section 3.2 of API RP 1162 lists examples of emergency officials and stakeholders that pipeline operators should invite to participate in this program. The recommended list of stakeholders includes fire departments, police and sheriff's departments, members of local emergency planning committees, and county and state emergency management agencies. However, 911 emergency call and dispatch centers and emergency communications agencies are not identified in API RP 1162 as stakeholders.

Dixie's Public Education Program

Dixie used API RP 1162 as a model for the content and organization of its public education program. Dixie submitted its program to PHMSA for review on September 5, 2006. On August 31, 2007, Dixie received confirmation from PHMSA that its review of Dixie's plan

had been completed and that PHMSA had found six areas that that needed improvement before the plan would be approved. After Dixie submitted revisions in these areas, PHMSA approved the plan on September 5, 2007, and noted that the plan complied with API RP 1162.

Safety Literature Distribution. The core element of Dixie's public education program was the distribution of safety literature to identified stakeholders that include residents, businesses, emergency response agencies, excavators, and public officials. Under the plan, Dixie mailed pipeline public awareness and safety literature each year to all emergency response officials and excavators in the county, every 2 years to the residents and businesses located within 1 mile on either side of the pipeline, and every 3 years to public officials within the county.

Dixie did not mail the literature itself; instead, it relied upon contractors to acquire the mailing data and mail the literature. Dixie did not exercise any oversight of its contractors to ensure that the mailings were accurate, nor did Dixie survey residents and businesses about the content of the mailings to determine their effectiveness.

In May 2007, Paradigm Alliance, Inc. (Paradigm), a contractor for Dixie, reported that it had mailed 258,284 copies of the brochure, *A Public Service Message—Pipeline Safety is Everyone's Responsibility*, to all stakeholders, including the residents and businesses within 1 mile of the pipeline in the Carmichael area. Paradigm used mailing data provided by a second company, Tele Atlas. On November 4, 2007, 3 days after the accident, Dixie's public awareness and damage prevention coordinator discovered that 10 addresses on County Road 621 were missing from the mailing data used by Paradigm in the May 2007 mailing. The 10 addresses included those of the houses and one business on County Road 621 that were destroyed and most heavily damaged in the Carmichael accident. Also, the houses on County Road 621 that were missed in the 2007 mailing included the homes of the two fatalities. In February 2008, Paradigm wrote to Dixie to explain why the addresses had been missed and confirmed that the error had been corrected. Paradigm told Dixie that, in May 2007, it had used one street database to identify the stakeholders within the 1-mile buffer around the Dixie pipeline. For its database, Paradigm had used a street *GeoCoding Index*, produced by Tele Atlas, which reversed the address range along County Road 621, incorrectly placing 10 houses on County Road 621 outside of the 1-mile buffer zone. Therefore, none of these addresses received the May 2007 mailing.

To minimize the possibility of this error occurring again, Paradigm said it plans to use two street databases and one parcel point database to analyze addresses. Any address that falls within the 1 mile buffer in any one of these three databases will be included in the mailing. A residential address will be excluded from the mailing only when all three databases show the address as outside the 1-mile buffer.

Because of the accident in Carmichael and the addresses missed from 2007, Dixie conducted a second mailing in June 2008 to all stakeholders, including residences and businesses that otherwise would not have received another mailing until 2009. In addition, Dixie has developed a process to validate the accuracy of its mailing list. For each of many randomly selected sample locations along the pipeline, Dixie will select an address within a 1-mile radius

and cross-reference the addresses with the mailing list provided by Dixie's mailing contractor. The process of compiling addresses for this validation process began in September 2009.

Dixie told the NTSB and PHMSA in January 2009 about the addresses missed in 2007, after Dixie's public awareness coordinator realized that they had not been told after the accident about the missed addresses. As a result of this oversight, PHMSA stated that it is evaluating the circumstances as a possible regulatory violation. According to a PHMSA representative, as of April 2009, PHMSA is considering the following:

- Conducting some targeted public awareness inspections, because of the long time between the June 2006 date for operators to have completed their public education plans and the June 2010 date for their first evaluation of these plans. Such inspections may follow the guidelines PHMSA used to evaluate the plans originally submitted by the operators.
- Issuing an advisory bulletin to remind operators that their public awareness programs are intended to show continuous improvement and that operators should not wait until the full 4 years have elapsed before evaluating and modifying their plans to make them more effective.
- To provide better enforcement guidance for inspectors, undertaking research to determine an acceptable percentage of residences, businesses, emergency responders, excavating contractors, public officials, and other stakeholders that an operator could be expected to identify and reach through the use of mailings based on a variety of databases.

As of September 2009, PHMSA has not completed action on these initiatives.

Outreach to Emergency Response Agencies. Under its Government Liaison-Emergency Response Program, Dixie conducted, through a technical contractor, periodic familiarization events. These events were for fire and rescue departments, law enforcement, members of local emergency planning committees, and regional emergency management and support organizations, such as the Red Cross, in the eight Mississippi and Alabama counties in which Dixie had pipeline facilities.³⁰ However, emergency services communications agencies, such as 911 emergency call and central dispatch centers, were not specifically identified as stakeholders in Dixie's public education program plan.

Three Government Liaison-Emergency Response Program training sessions were held in Meridian, Mississippi, on April 26, 2005, April 18, 2006, and April 5, 2007. This training consisted of a lecture and was offered to local emergency response agencies in Clarke County and the other regional counties in Mississippi and Alabama. Dixie also conducted a training

³⁰ Dixie's pipelines ran through Clarke, Jasper, Kemper, Lauderdale, Neshoba, Newton, and Scott Counties in Mississippi and Choctaw County in Alabama.

exercise in August 2006 at Waynesboro, Mississippi, which is about 25 miles south of Carmichael. The scenario of the half-day exercise involved the simulation of a high-pressure liquid propane pipeline rupture caused by an unauthorized excavation, resulting in a release of product, fire, and injuries. The scope of the exercise required a comprehensive emergency response and involved the participation of fire and rescue departments, police departments, ambulance services; the exercise of incident command and mutual aid protocols; and pipeline operator response.

Dixie distributed three publications to address emergency response procedures to those emergency response organizations that participated in drills, exercises, and training events. Dixie also mailed these publications to those agencies and organizations identified as stakeholders that did not participate in the training events. The first publication was *The Pipeline Group Emergency Response Manual*. The second publication, *General Information Guide to a Pipeline Emergency*, is essentially identical to parts of the publication, *Emergency Response Guidebook*, that is available from the DOT. There is some overlap of information between these two publications.

A third publication, *A Guideline for Emergency Response Agencies*, included general information about Dixie's overall pipeline operation, a summary of the chemical properties and characteristics of propane, and basic instructions for responding to an emergency event involving the pipeline. This also was distributed to the emergency response agencies participating in the Government Liaison-Emergency Response Program training sessions. This publication included specific guidelines for recognizing the significant signs of a massive propane gas pipeline release, including the presence of a dense white cloud or fog accompanied by a roaring sound, and instructions for a pipeline emergency that could serve as guidance to 911 operators on what to tell callers to do immediately to avoid danger. Specifically, in the event of a large flammable gas release, the guidance suggests the elimination of potential ignition sources, such as an open flame, a lighted cigarette, and starting a vehicle, and the immediate evacuation of the area to an upwind location. Also, the guidance includes basic procedures for emergency response agencies, including implementing an immediate evacuation and identifying the appropriate technical resources that need to be requested from the pipeline owner.

Emergency Response Agency Participation. Table 3 shows the participants from Clarke County in the emergency response training held in Meridian in the 3 years before the accident.

Table 3. Clarke County Participation in Training Sponsored by Dixie.

Year	Attendees		
	CVFD	Sheriff's Department	Emergency Management
2005	2	0	0
2006	0	0	2
2007	2	1	2

No member of the CVFD attended the 2006 exercise in Waynesboro. CVFD officials reported that the CVFD had not participated in any formal hands-on preparedness training with Dixie in the 5 years before the accident. However, the CVFD officials stated their belief that all CVFD firefighting operations personnel have a basic familiarization with the Dixie propane pipeline operation in their jurisdiction and that the lack of familiarization training was not an impediment and did not result in an unwarranted risk to their personnel or the civilian population in this accident. The CVFD officials stated that they would make an effort to incorporate more simulated table-top tactical response drills involving the release and ignition of propane gas from a pipeline in upcoming preparedness training sessions.

Clarke County Central Dispatch personnel did not receive familiarization training sponsored by Dixie that specifically covered the operation of a propane or other large pipeline, nor did they receive Dixie's booklet, *A Guideline for Emergency Response Agencies*, or the other two safety publications that Dixie routinely distributed to emergency response agencies. Further, the initial training and qualification of Clarke County Central Dispatch operating personnel does not address pipeline emergencies. The training consists of both formal classroom instruction and an on-the-job instructional regimen in which new personnel are closely monitored and supervised by experienced operating personnel. The classroom and on-the-job training includes instruction about processing emergency calls and about obtaining information from callers regarding the nature of the incident, the location, and the current situation. Trainees also receive guidance about providing instructions to the caller to avoid or escape from danger or harm. Trainees also receive information about available resources, such as caller ID and maps, that may be useful in responding to emergency calls.

Clarke County Central Dispatch personnel also have not participated in drills and exercises simulating a propane pipeline rupture, a substantial product release, and subsequent ignition and fire. In the 3 years before the accident, Clarke County Central Dispatch personnel had not participated in the emergency responder outreach program conducted or sponsored by Dixie. Clarke County Central Dispatch personnel have routinely participated in scheduled preparedness drills and training exercises that have been conducted on the local level within Clarke County and on occasion by neighboring counties and state agencies, such as the highway patrol. However, there is no indication that any of these exercises involved a pipeline accident or emergency.

Clarke County Emergency Management and Communications

Emergency Management

Clarke County is governed by a Board of Supervisors. Three primary county emergency response agencies that are autonomous and under the direct supervision of the Board of Supervisors are the Clarke County Emergency Management Agency, Clarke County Central Dispatch, and the Clarke County Sheriff's Department.

Various volunteer fire departments and emergency medical units within the county provide fire and rescue emergency services; however, these departments are not under the Clarke County Board of Supervisors. The CVFD is a fully volunteer department with 17 active members that provides fire and rescue protection for about 38 square miles of Clarke County. The CVFD is under the command of the chief of the department, who is supported by an assistant chief. The CVFD has three vehicles—one pumper truck and two tanker trucks.

Emergency Communications

Communications for all emergency services within Clarke County (that is, all fire and rescue, sheriff's department, emergency medical services [ambulance], and emergency management) are performed by the Clarke County communications agency through its operation of the 911 emergency call and central dispatch center. Clarke County Central Dispatch typically has two qualified 911 operators on duty at all times. An operational supervisor, who is also fully qualified to perform all operational duties, is usually present during daylight hours.

Telephone requests for emergency services in Clarke County, are received and processed by Clarke County Central Dispatch, which does not have a computer-aided dispatch system. Procedurally, for fire and rescue operations, initial dispatching is done manually by transmitting a page over the fire department radio channel to the appropriate county fire department. Information about the emergency location and type is then relayed by voice over a conventional service radio to responding fire department personnel who received the communication via units installed in fire trucks, hand-held service radios, and/or base station radio units in fire stations.

Clarke County Central Dispatch uses a conventional service radio communication system for routine mobile communications with the emergency services agencies of the county. A radio signal repeater is used by Clarke County Central Dispatch because the range of the service radio main transmitter is not sufficient to cover the area of the entire county.

Clarke County's radio communication system, including the fire and rescue and sheriff's department radio signal repeater equipment, is maintained by a maintenance service contractor. The radio signal repeater equipment in use at the time of the accident was installed in June 2007 and had not experienced any system malfunctions or performance failures until November 1, 2007. Separate radio signal repeater transmitter units operating on different frequencies are used

to transmit fire and rescue radio signal communications and the sheriff's department radio signal communications. The service radio equipment in all fire department and sheriff's department vehicles can be switched to either department's frequency. However, the fire department and the sheriff's department do not routinely monitor the other's radio frequency. Fire and sheriff's department personnel must be directed to switch frequencies in order to establish radio communications.

Analysis

Exclusions

One call reports, aerial patrol reports, and pipeline contact reports since 2005 for the Dixie pipeline were reviewed for indications of past excavation activity in the vicinity of rupture, and no instances of excavation activity were found. No grooves or gouges were found on the ruptured portion of the pipe during the laboratory examination. The two nearly parallel scratch marks on the outside surface of the ruptured pipe joint were not near the rupture and thus not involved in the fracture. No significant inward denting of the pipe wall was observed near the scratch marks. Neither the longitudinal nor the girth weld fracture was adjacent to or intersected the scratch marks. Therefore, damage from third-party activity was ruled out as a factor in the cause of the rupture.

The annual corrosion survey reports for the pipeline in the vicinity of the rupture were reviewed, and no problems associated with cathodic protection were found. No external or internal corrosion was observed on the ruptured pipe during the field investigation. During the laboratory examination, no corrosion damage was observed on the fracture surfaces of the ruptured pipe, and fractographic examination showed no indication of stress corrosion cracking. Therefore, degradation of the pipeline from corrosion was eliminated as a factor in the cause of the rupture.

The pipeline controller on duty at the time of the accident was adequately trained. The controller was not affected by fatigue, illicit drugs, alcohol, or medications, and he was fit for duty when the accident occurred. He detected and identified the leak in the pipeline system in a timely manner. The pipeline controller used information from the SCADA system, from people in the Carmichael area, and from personnel at the control center to respond efficiently to the emergency situation. Therefore, the actions of the pipeline controller on duty were ruled out as a factor in the cause of the rupture. The pipeline was operating under normal operating conditions, and no unusual conditions, such as pipeline overpressure or an equipment failure, were detected in the system at the time of the accident that could have caused or contributed to the accident. The NTSB, therefore, concludes that corrosion, excavation damage, the controller's actions, and the operating conditions of the pipeline were not factors in the accident.

The pipeline rupture occurred at 10:35:02 a.m. The first 911 call to Clarke County Central Dispatch was initiated at 10:39:56 a.m., and the second call concluded at 10:41:46 a.m. The ignition of the propane gas cloud occurred at 10:42:32 a.m. The interval between the end of the two 911 calls and the ignition of the propane was about 45 seconds. The NTSB concludes that the short interval between the conclusion of the 911 calls and the ignition of released propane was insufficient time for the CVFD and other emergency response agencies to evacuate the area before the explosion and fire. Decisions made by and actions of the emergency responders regarding initial fire suppression efforts and the immediate search for and evacuation

of residents near the rupture site and the decision to allow the residual propane in the pipeline to continue to burn until it self-extinguished minimized the risk to emergency responders and the public. The NTSB concludes that the actions of the Clarke County Sheriff's Department, the CVFD, and other fire departments and agencies responding under mutual aid agreements were timely, well executed, and effective.

Fracture of the Pipeline

The fracture extended along the entire length of the longitudinal ERW seam of the ruptured pipe joint. Regions of the fracture faces along the longitudinal seam weld followed the upturned grains that resulted from the ERW process, with fracture paths similar to hook cracks and with repeated patterns transverse to the wall thickness that are consistent with stitching in ERW pipe. The Charpy testing showed that the ERW seam was less resistant to crack propagation than the base metal, which is to be expected for this type of pipe.³¹

The precise location where the fracture initiated could not be identified through fractographic examination of the ruptured pipe. This is not unusual, and PHMSA noted that, for ERW seam ruptures, the identification of a definitive fracture origin is not possible in many cases. Further, the review of information on numerous ERW seam fractures from hydrostatic pressure tests of the Dixie pipeline shows that in many cases the failures examined had no obvious point of fracture origin.

Examination of a pipe joint that failed during a postaccident hydrostatic pressure test on November 8, 2007, revealed fracture features similar to the accident fracture. The test fracture was along the longitudinal ERW seam as was the accident fracture. Also like the accident fracture, the fracture faces of the test fracture contained the island-like features that are associated with hook cracks. The test fracture also lacked features indicative of the fracture origin.

Although the fracture faces in the accident pipe revealed multiple features of interest, they were degraded by oxidation damage resulting from the fire that occurred after the propane ignited. The lack of well-defined fractographic features to pinpoint the location where the fracture initiated led investigators to use finite element analysis (simulation) to further explore possible fracture origination sites. Two possible scenarios for the origin of the pipeline fracture were considered in the finite element analysis:

- A crack originated in or near the longitudinal seam weld.
- A crack originated in the upstream girth weld.

³¹ Cold welds, stitching, hook cracks, and other undesirable flaws in ERW steel pipeline longitudinal welds can adversely affect Charpy V-notch toughness.

Numerous computational simulations were performed in an attempt to replicate the residual pipe deformation patterns in the accident pipe. On the upstream side of the ruptured pipe joint, the fracture followed the circumferential girth weld for about 3 inches and then continued diagonally about 12 inches into the base metal of the adjacent pipe joint, leaving an open flap of pipe at the upstream girth weld. A primary objective of the finite element simulations was to replicate the shape of the upstream end of the pipe joint including the open flap.

A series of finite element simulations that assumed fracture initiation in the girth weld predicted pipe deformation patterns consistent with those observed in the accident pipe in the region around the upstream girth weld. The simulations that assumed fracture initiation in the girth weld also predicted a stress state consistent with the generation of the distinct chevron pattern observed in the circumferential fracture as it transitioned into the upstream pipe joint. However, the simulations that assumed fracture initiation in the seam weld did not predict pipe deformations consistent with those observed in the accident pipe near the upstream girth weld.

To evaluate the likelihood of one scenario over the other, the NTSB closely examined all available evidence. The NTSB also evaluated submissions received from two parties to the investigation, PHMSA and Dixie. Both parties indicated in their submissions that the pipeline rupture was most likely due to a fracture initiating in the longitudinal ERW seam. In the submission from Dixie, one of Dixie's contractors stated that initiation in the girth weld could not be ruled out.

No confirmed in-service pipeline failures in girth welds have been reported for the entire pipeline since it was installed in 1961. A review of the past failures experienced during hydrostatic pressure testing since the pipeline was installed shows that the vast majority of the failures have involved the ERW seam, with only one failure at a girth weld (recorded as a seeping leak at a field weld that Dixie indicated was likely a girth weld) that occurred in 1984.

Although the specific region in the accident pipe where the fracture initiated could not be located, fractographic examination did reveal multiple features consistent with the scenario in which the fracture initiated in the ERW seam. Examination of the fracture faces of the longitudinal seam revealed two areas with chevron pattern fragments within about 4 inches of the upstream girth weld. The orientation of these chevron patterns indicated that the fracture was propagating in the upstream direction along the longitudinal seam toward the girth weld. Also, in the region where the fracture transitioned between the ERW seam and the upstream girth weld, a branching crack feature was noted that indicates fracture propagation in the upstream direction, toward the girth weld. The examination of the downstream face of the girth weld fracture revealed that a 1-inch fracture portion adjacent to the ERW seam fracture contained chevron pattern fragments indicating that the fracture was propagating away from the longitudinal seam. Finally, an examination of the fracture faces in the upstream girth weld showed no evidence of a preexisting crack. The NTSB, therefore, concludes that the pipe contains multiple fracture features that indicate that a crack initiated in the longitudinal seam weld; however, finite element simulations raise the possibility that a crack could have initiated in the upstream girth weld.

Safety and Performance of ERW Pipe

PHMSA's data from 2002 through 2007 indicate that there were 19 hazardous liquid pipeline incidents involving failures of seam welds in both low- and high-frequency ERW pipe. According to PHMSA, although ERW pipe failures are relatively infrequent, they tend to be catastrophic. PHMSA further noted that pre-1970 low-frequency ERW pipe has a much higher failure rate than newer ERW pipes and that the quality of low-frequency ERW pipe can vary from manufacturer to manufacturer. ERW pipe constituted 68 percent of the total miles of hazardous liquid pipelines in 2007. Additionally, about one-fourth of the low-frequency and about one-half of the high-frequency ERW pipelines transport highly volatile liquids, such as propane and anhydrous ammonia. As these pipelines age and cumulative pressure cycles increase, the failure incidence may also increase.

Identifying the causes and the initiation sites of pipeline fractures is important for understanding the factors that are involved in and contribute to pipe failures. Even more important is to be able to locate a critical flaw or condition before it leads to a catastrophic failure, such as occurred in Carmichael. Currently, most pipeline operators rely upon in-line inspections to identify, detect, and monitor the growth of potential defects in their pipeline systems. In-line inspections are conducted to detect and size the anomalies that may be present in the pipe wall. The data then can be analyzed to evaluate the severity of the anomalies (that is, the size [length and depth] and the rate of growth). The data can be used by a pipeline operator to establish a schedule to repair or remove the pipeline before an anomaly grows to a critical size and causes a pipe rupture.

Segments of the Carmichael pipeline had been inspected using in-line inspection tools multiple times in the 9 years before the November 2007 rupture. In 1998, Tuboscope Vetco Pipeline Services inspected the pipeline segment from Hattiesburg to Demopolis, using a first-generation metal-flux leakage tool to search for evidence of metal loss caused by internal corrosion. The test did not find any anomalies related to metal loss in the pipe joint that ruptured in this accident.

In 2005, Dixie conducted a special ERW seam integrity assessment over the entire Hattiesburg-to-Demopolis segment, using the GE UltraScan crack detection tool that can detect defects in the pipe in the longitudinal direction. This tool is not designed to detect circumferentially oriented defects in the girth welds. This inspection identified 21 pipe joints with reportable indications, and Dixie removed all 21 pipe joints, including the girth welds on each end of each joint, as part of its pipeline integrity repair program. The inspection also identified two features in the pipe joint that ruptured at Carmichael, but the features did not meet the criteria for reportable indications and were not factors in the accident.

In 2006, Magpie inspected the Hattiesburg-to-Demopolis pipeline segment, using a geometry tool followed by a high-resolution axial magnetic flux leakage metal loss tool to detect metal loss in the pipe. The latter tool is used to detect metal loss in or near the girth weld. Magpie reported no geometric anomalies and detected no metal-loss-related anomalies in the joint that ruptured in Carmichael.

The results of the three in-line inspections that were conducted in the 9 years before the accident found no defects or anomalies in the Carmichael pipe joint that could be correlated with the 2007 rupture. It is possible that detectable anomalies did not exist at the times of the three tests, or the inspection tools did not find detectable anomalies that may have existed, or anomalies existed below detection limits but grew at a very fast rate.

Dixie contracted with Stork to conduct hydrostatic pressure burst tests on the pipe joints and girth welds that had been removed after the 2005 in-line inspection. All 21 pipe joints ruptured during the burst tests at pressures ranging from 2,055 psig to 3,250 psig. Over this pressure range, ruptures occurred above the specified minimum yield strength. Stork's conclusions after examination of the ruptures show the difficulty of identifying fracture origins in ERW pipe. For a majority of the 21 pipe joints, Stork identified a general region or area of the fracture surface as the origin of the fracture when an apparent fracture origin was not identifiable. The fracture surface of only one pipe joint had a hook crack with chevrons on each side pointing to the fracture initiation site.

Stork also correlated the location of the identified fracture origin for the pipe joints with indications reported from the 2005 in-line inspection. Stork found that for 12 of the 21 ruptures, an indication from the 2005 in-line inspection coincided with either an identified fracture origin or a point on the fracture surface. No reportable indications were found during the in-line inspection for 9 of the 21 ruptured pipe joints.

The accumulated data from the three in-line inspections of the Carmichael pipeline and from the examination of the pipe joints that were removed and subjected to hydrostatic testing illustrate the limitations of current in-line inspection technology for detecting significant flaws in low-frequency ERW pipe. PHMSA believes that in-line inspection technology is improving and data analysis capabilities are increasing each year. Reliable and effective in-line inspection tools have become more critical in recent years as the focus of the pipeline safety program has shifted to risk-based integrity management plans that are developed and implemented by individual pipeline operators. The NTSB concludes that current inspection and testing programs are not sufficiently reliable to identify features associated with longitudinal seam failures of ERW pipe prior to catastrophic failure in operating pipelines.

Hydrostatic pressure tests have been effective in eliminating potentially critical anomalies leading to in-service ruptures. However, these tests may cause some anomalies to grow to a critical size much faster than they might have without a hydrostatic test. The tests also introduce water into the pipeline, requiring action to prevent internal corrosion.

According to PHMSA, the pressure spike test is also beneficial because it subjects a pipeline to a higher pressure for a shorter time than the standard hydrostatic test. The rationale is that higher pressure is more likely to cause critical cracks to fail, while the shorter time limits the potential for smaller cracks to grow during the test. Although PHMSA has been requiring operators to conduct a spike test before returning a pipeline to service following a failure, the spike test is not being used in place of the hydrostatic test or conducted on a periodic basis. PHMSA has stated that it is examining these methods and may require them after pipeline

failures. PHMSA is also examining methods that operators can use to minimize pressure cycling in low-frequency ERW pipelines to reduce fatigue on the pipeline. The NTSB recommends that PHMSA conduct a comprehensive study to identify actions that can be implemented by pipeline operators to eliminate catastrophic longitudinal seam failures in ERW pipe; at a minimum, the study should include assessments of the effectiveness and effects of in-line inspection tools, hydrostatic pressure tests, and spike pressure tests; pipe material strength characteristics and failure mechanisms; the effects of aging on ERW pipelines; operational factors; and data collection and predictive analysis.

Pipeline Operator Public Education Programs

The NTSB has long been concerned about pipeline operators' public education programs, including the content, distribution, and effectiveness of pipeline operators' safety materials for both hazardous liquid and natural gas pipelines. From the late 1980s through the late 1990s, the NTSB investigated several accidents³² in which deficiencies in operators' public education programs were safety issues. In the report of the investigation of the pipeline rupture, liquid butane release, and fire in Lively, Texas, on August 24, 1996, the NTSB concluded that requirements for the content, format, and periodic evaluation of public education programs can help pipeline operators ensure that their programs are effective. The NTSB made the following recommendations to PHMSA:

P-98-37

Revise 49 *Code of Federal Regulations* Part 195 to include requirements for the content and distribution of liquid pipeline operators' public education programs.

P-98-38

Revise 49 *Code of Federal Regulations* Part 195 to require that pipeline operators periodically evaluate the effectiveness of their public education programs using scientific techniques.

The NTSB classified both recommendations "Closed—Acceptable Action" on November 21, 2003, based on various PHMSA initiatives with the natural gas and hazardous liquid pipeline industries. PHMSA's initiatives included assisting with the development and adoption of consensus standards embodied in API RP 1162, committing to incorporate the consensus standards by reference into the pipeline safety regulations (49 CFR Parts 192 and

³² Pipeline Accident Report—*Kansas Power and Light Company Natural Gas Accidents, September 16, 1988 to March 29, 1989* (NTSB/PAR-90/03); Pipeline Accident Report—*Texas Eastern Transmission Corporation Natural Gas Pipeline Explosion and Fire, Edison, New Jersey, March 23, 1994* (NTSB/PAR-95/01); Pipeline Accident Report—*San Juan Gas Company, Inc./Enron Corp., Propane Gas Explosion in San Juan, Puerto Rico, on November 21, 1996* (NTSB/PAR-97/01); and Pipeline Accident Summary Report—*Pipeline Rupture, Liquid Butane Release, and Fire, Lively, Texas, August 24, 1996* (NTSB/PAR-98/02/SUM).

195), assisting pipeline operators in aligning their existing public education programs with API RP 1162, and conducting workshops to facilitate operators' understanding of API RP 1162.

The problems with Dixie's public education program that were uncovered in this investigation and documented in this report led the NTSB to reassess the public education standards and oversight.

Public Awareness Program

Dixie's public awareness program distributed safety literature to identified stakeholders that include residents, businesses, emergency response agencies, excavators, and public officials. Under the program, Dixie, through its contractor, mailed pipeline public awareness and safety literature each year to all emergency response officials and excavators in the county, every 2 years to the residents and businesses within 1 mile of either side of the pipeline, and every 3 years to public officials within the county. After the accident, Dixie discovered that 10 addresses on County Road 621 were missing from the mailing data used for the May 2007 distribution of *A Public Service Message—Pipeline Safety is Everyone's Responsibility*; the 10 addresses included the houses of the two fatalities and the houses and one business on County Road 621 that were destroyed and most heavily damaged in the Carmichael accident.

Dixie has told investigators that since the accident, its contractor has corrected the mailing data. Also, Dixie planned a second mailing to all stakeholders, including those that had been missed previously. These actions are responses to specific problems identified in Dixie's public education program and cannot be considered as active oversight of its program. Before the accident, Dixie relied upon its contractors to obtain accurate mailing data and ensure the mailings to the public were completed. Dixie did not perform oversight to ensure that all appropriate recipients were on the mailing lists and that the mailings met its requirements and those of API RP 1162, nor did it initiate actions to evaluate the effectiveness of the program. For example, Dixie did not conduct customer surveys to verify that the mailing lists were complete, that mailings had been received, and that customers understood the guidance contained in the safety literature mailed to them. Without such efforts, Dixie could not accurately assess the effectiveness of its public awareness program as required under federal pipeline standards (49 CFR Parts 192 and 195) and API RP 1162.

Outreach Program to Emergency Responders

Dixie's outreach program to emergency response agencies provided opportunities for emergency responders in Clarke County and neighboring counties to receive familiarization training and participate in exercises related to the propane pipeline so that they would be prepared in case of accident or emergency. In addition, the safety literature and guidance that training participants and invitees received contained important information about the hazards of propane and actions to protect the public and emergency responders. These materials also contained specific guidance that 911 operators could use to recognize the signs of a massive

propane release and the information to give to callers so they can avoid danger during such a release. Dixie did not identify central dispatch centers, such as Clarke County Central Dispatch, as stakeholders and participants in its outreach program for emergency response agencies. In the 3 years before the Carmichael accident, employees of the Clarke County Sheriff's Department, the County Emergency Management Agency, and the CVFD attended Dixie's emergency response training sessions, but Clarke County Central Dispatch was not included in the list of attendees to this type of session and the Clarke County 911 operators did not attend. API RP 1162, the pipeline industry's standard for public education programs, did not identify central dispatch centers as organizations to contact although Dixie, as a regional pipeline operator, had the responsibility to identify and offer training to the appropriate emergency response agencies in those regions in which it operates. Had personnel from Clarke County Central Dispatch participated in Dixie's periodic familiarization training or received the guidance to 911 operators, they may have promptly recognized that the information initially reported indicated a massive propane release in the area and would have been better prepared to address it. Such actions may have included warning callers to avoid ignition sources and telling them to immediately evacuate the area.

Because addresses were omitted from public awareness mailing lists and 911 operators were not invited to attend the outreach program for emergency responders, the NTSB concludes that Dixie Pipeline Company's oversight and evaluation of the effectiveness of its public education programs were inadequate. The NTSB recommends that the Dixie Pipeline Company take measures to determine that all residences and businesses within its operating regions are included on its mailing list and receive mailings of safety guidance information. The NTSB further recommends that the Dixie Pipeline Company implement procedures to evaluate the effectiveness of its public education program. Regarding outreach to emergency response agencies, the NTSB recommends that Dixie Pipeline Company verify that all 911 emergency centers within its operating regions are included on its mailing list, invited to participate in operator-sponsored training activities, and receive mailings of safety guidance information.

The circumstances of the Carmichael accident, particularly the lack of training and guidance for the Clarke County Dispatch Center about propane pipeline operations, raise concerns about the adequacy of API RP 1162 and oversight by operators and PHMSA to ensure effective public education programs are implemented and followed. The section of API RP 1162 pertaining to outreach programs to emergency response agencies identifies the following as attendees and participants:

Fire departments, Police/Sheriff departments, [local emergency planning committees], County and State Emergency Management Agencies, other emergency response organizations, and other public safety organizations.

Although it is reasonable to interpret "other emergency response organizations" to include emergency 911 dispatch centers, there is no certainty that such an interpretation will be universal, as exhibited in this accident. Emergency 911 dispatch centers in many jurisdictions are part of either the fire or the police department. In areas of the country that are served by volunteer fire departments, there may be a greater possibility that the local 911 dispatch center is

independent from the fire and police departments. In such instances, a pipeline operator may overlook the inclusion of an independent 911 center as a potential attendee and participant in its outreach program. The NTSB concludes that the absence of emergency 911 dispatch centers from the list of stakeholders in API RP 1162 increases the possibility that 911 dispatch center personnel might not receive the necessary training to recognize the hazards of a large release of propane and other flammable products from a pipeline and thereby be able to warn 911 callers of imminent danger. Therefore, the NTSB recommends that the API revise API RP 1162 to explicitly identify 911 emergency call centers as emergency response agencies to be included in outreach programs under a pipeline operator's public education program.

The timetable set forth in PHMSA's final rule published in May 2005 gave pipeline operators until June 2006 to develop public education programs and, in supplemental guidance following publication of the final rule, until June 2010 to evaluate the effectiveness of those programs. After Dixie acknowledged in January 2009 that it had failed to tell the NTSB and PHMSA about the addresses missed in the May 2007 mailing, PHMSA began to consider possible actions to assess operators' self-evaluations of the effectiveness of their public awareness program plans. The actions under consideration include conducting targeted public awareness inspections, issuing an advisory bulletin urging pipeline operators to conduct their self-evaluations and modify their plans before the 2010 deadline, and initiating research about effectively reaching the public with the appropriate safety information. However, PHMSA has not completed action on these initiatives. The Carmichael accident has shown that although an operator's public awareness program plan may meet API RP 1162 requirements and federal pipeline standards, this is not a guarantee that implementation of the program is effective or that the operator is exercising sufficient oversight. The NTSB recommends that PHMSA initiate a program to evaluate pipeline operators' public education programs, including pipeline operators' self-evaluations of the effectiveness of their public education programs, and provide the NTSB with a timeline for implementation and completion of this evaluation.

Clarke County Emergency Communications

Preparedness of Clarke County 911 Dispatch Center

The first call reporting a gas explosion to Clarke County Central Dispatch came in about 5 minutes after the pipe rupture, and the ignition of the released propane occurred about 2 1/2 minutes after that. Although Clarke County Central Dispatch personnel paged fire resources to respond to the scene and told the caller that a fire truck was on its way, they did not tell the caller what to do in the meantime to respond to the emergency. With the circumstances of this accident, however, even if the dispatcher receiving the call had instantly recognized the impending danger, warned the caller not to use any ignition sources, and directed the caller to immediately evacuate and get away from the gas cloud, the caller at best had very little time to reach safety before the ignition and fire. Nevertheless, Clarke County Central Dispatch personnel need to be able to assess the significance of telephoned descriptions of pipeline emergencies so that they can give callers the correct information about how to keep themselves safe. Heightened

awareness and knowledge attained through appropriate training and participation in drills involving pipeline operators and other local emergency response agencies can improve the ability of Clarke County Central Dispatch to provide timely information and guidance to citizens and county emergency response agencies in future emergencies. The NTSB concludes that at the time of the accident, the Clarke County Central Dispatch emergency 911 personnel were not sufficiently knowledgeable about the dangers of a large release of propane and the appropriate actions to take. The NTSB recommends that the Clarke County Board of Supervisors require and document that the Clarke County Central Dispatch emergency 911 personnel receive regular training and participate in regional exercises and drills pertaining to pipeline safety.

Emergency Radio Communications

About 1 1/2 hours before the accident, the radio signal repeater for the fire department, the primary radio system for Clarke County Central Dispatch, was not working, but dispatch personnel were not aware of this. (Communication cables of the radio signal repeater equipment had been inadvertently disconnected during routine housekeeping earlier that morning.) After Clarke County Central Dispatch began receiving 911 calls, an operator promptly sent a page to the CVFD to respond. When acknowledgements from CVFD were not received as required, dispatch center personnel began to contact nearby fire departments in accordance with their operational protocol and mutual aid agreements. However, when fire department personnel failed to acknowledge the pages, the dispatch center personnel did not immediately recognize the possibility of a communications equipment problem.

It was not until about 10:55 a.m., or about 15 minutes after the first 911 call was received at the dispatch center, that the Clarke County sheriff, who was monitoring the radio communications, contacted the dispatch center through a deputy and informed the dispatch center that the primary fire and rescue radio signal repeater appeared not to be working. About the same time, dispatch center personnel began to suspect a malfunction of the radio signal repeater and switched to the backup system, which was working.

Despite the radio communications problem, the CVFD became aware of the event when the assistant chief of the CVFD heard the explosion at 10:43 a.m., saw a large fireball plume and a cloud of heavy black smoke in the east seconds later, and then promptly mobilized resources and responded to the accident scene. By about 10:55 a.m., CVFD personnel and fire trucks were at the accident scene. Consequently, the NTSB concludes that despite the failure of Clarke County Central Dispatch to immediately recognize that its primary radio communications system was not working, the CVFD was able to respond to the accident in a timely manner. Since the accident, the Clarke County government has fixed the problem of inadvertent cable disconnection that caused failure of the primary system and is considering further enhancements to the communications system. Specifically, since the accident, Clarke County Central Dispatch conducts bi-weekly tests of the radio repeater system to ensure it is performing normally and has modified the connection hardware to cable connector fittings and connection sockets that have positive engaging, screw-type locking features to help prevent future inadvertent disconnections

of the communication cables. Because these actions sufficiently address this problem, the NTSB does not believe a safety recommendation in this area is needed.

Conclusions

Findings

1. Corrosion, excavation damage, the controller's actions, and the operating conditions of the pipeline were not factors in the accident.
2. The short interval between the conclusion of the 911 calls and the ignition of released propane was insufficient time for the Carmichael Volunteer Fire Department and other emergency response agencies to evacuate the area before the explosion and fire.
3. The actions of the Clarke County Sheriff's Department, the Carmichael Volunteer Fire Department, and other fire departments and agencies responding under mutual aid agreements were timely, well executed, and effective.
4. The pipe contains multiple fracture features that indicate that a crack initiated in the longitudinal seam weld; however, finite element simulations raise the possibility that a crack could have initiated in the upstream girth weld.
5. Current inspection and testing programs are not sufficiently reliable to identify features associated with longitudinal seam failures of ERW pipe prior to catastrophic failure in operating pipelines.
6. Dixie Pipeline Company's oversight and evaluation of the effectiveness of its public education programs were inadequate.
7. The absence of emergency 911 dispatch centers from the list of stakeholders in American Petroleum Institute Recommended Practice 1162 increases the possibility that 911 dispatch center personnel might not receive the necessary training to recognize the hazards of a large release of propane and other flammable products from a pipeline and thereby be able to warn 911 callers of imminent danger.
8. At the time of the accident, the Clarke County Central Dispatch emergency 911 personnel were not sufficiently knowledgeable about the dangers of a large release of propane and the appropriate actions to take.
9. Despite the failure of Clarke County Central Dispatch to immediately recognize that its primary radio communications system was not working, the Carmichael Volunteer Fire Department was able to respond to the accident in a timely manner.

Probable Cause

The National Transportation Safety Board determines that the probable cause of the November 1, 2007, rupture of the liquid propane pipeline operated by Dixie Pipeline Company near Carmichael, Mississippi, was the failure of a weld that caused the pipe to fracture along the longitudinal seam weld, a portion of the upstream girth weld, and portions of the adjacent pipe joints.

Recommendations

As a result of its investigation of the November 1, 2007, rupture of the liquid propane pipeline operated by Dixie Pipeline Company the National Transportation Safety Board makes the following recommendations:

To the Pipeline and Hazardous Materials Safety Administration:

Conduct a comprehensive study to identify actions that can be implemented by pipeline operators to eliminate catastrophic longitudinal seam failures in electric resistance welded (ERW) pipe; at a minimum, the study should include assessments of the effectiveness and effects of in-line inspection tools, hydrostatic pressure tests, and spike pressure tests; pipe material strength characteristics and failure mechanisms; the effects of aging on ERW pipelines; operational factors; and data collection and predictive analysis. (P-09-1)

Based on the results of the study requested in Safety Recommendation P-09-1, implement the actions needed. (P-09-2)

Initiate a program to evaluate pipeline operators' public education programs, including pipeline operators' self-evaluations of the effectiveness of their public education programs. Provide the National Transportation Safety Board with a timeline for implementation and completion of this evaluation. (P-09-3)

To the Clarke County Board of Supervisors:

Require and document that the Clarke County Central Dispatch emergency 911 personnel receive regular training and participate in regional exercises and drills pertaining to pipeline safety. (P-09-4)

To the American Petroleum Institute:

Revise American Petroleum Institute Recommended Practice 1162 to explicitly identify 911 emergency call centers as emergency response agencies to be included in outreach programs under a pipeline operator's public education program. (P-09-5)

To Dixie Pipeline Company:

Take measures to determine that all residences and businesses within your operating regions are included on your mailing list and receive mailings of safety guidance information. (P-09-6)

Implement procedures to evaluate the effectiveness of your public education program. (P-09-7)

Verify that all 911 emergency centers within your operating regions are included on your mailing list, invited to participate in operator-sponsored training activities, and receive mailings of safety guidance information. (P-09-8)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

DEBORAH A.P. HERSMAN
Chairman

ROBERT L. SUMWALT
Member

CHRISTOPHER A. HART
Vice Chairman

Adopted: October 14, 2009

Appendix A

Investigation

The NTSB was notified of the rupture of the liquid propane pipeline operated by Dixie Pipeline Company about 12:53 p.m. on November 1, 2007. The investigator-in-charge and other investigative team members were launched from the NTSB's Washington, D.C., Headquarters office. Robert L. Sumwalt was the Board Member on scene. Investigative groups were formed for pipeline operations, metallurgy, human performance, and survival factors. The NTSB later established a group for in-line inspection factors. No hearing or depositions were held in conjunction with this accident.

Parties to the investigation included the Pipeline and Hazardous Materials Safety Administration, Dixie Pipeline Company, United States Steel Company, Clarke County Sheriff's Department, and Carmichael Volunteer Fire Department.

Appendix B

Accident Timeline

Day	Time	Event
Thursday November 1	10:35:02 a.m.	Rupture of 12-inch-diameter pipeline operated by Dixie Pipeline Company near Carmichael, Mississippi.
	10:35:13 a.m.	Pipeline controller in Houston, Texas, control center receives rate-of-change alarm on SCADA panel for Carmichael Pump Station.
	10:35:46 a.m.	Second rate-of-change alarm received for Butler Pump Station.
	10:35:50 a.m.	Rate-of-change alarm received for Yellow Creek Pump Station. Automatic shutdown of Carmichael Pump Station unit 2 pump.
	10:36:25 a.m.	Pipeline controller began to shut down pipeline.
	10:37:12 a.m.	Pipeline controller started a pump at Butler Station to pull product away from rupture area.
	10:38 a.m.	Controller started contacting field personnel from Hattiesburg and Demopolis Pump Stations to respond to release.
	10:39:56 a.m.	Clarke County Central Dispatch (Emergency 911) received call reporting gas explosion & white gas in the area but no fire. Clarke County Central Dispatch began to contact and dispatch police, fire, & rescue resources.
	10:40:13 a.m.	Clarke County Central Dispatch received call reporting pipeline release.
	10:41 a.m.	Dixie control center received call from resident near rupture site reporting pipeline release.
	10:43 a.m.	CVFD asst. chief heard distant explosion followed by plume and black smoke; began mobilizing CVFD fire apparatus and personnel to the scene.
	10:46 a.m.	Pipeline controller received call reporting four major explosions, fire 200 feet high, and two columns of white and black smoke. Controller identified location of leak as area where a Hunt pipeline crosses Dixie pipeline. Controller directed contractor in Carmichael area to the site.
	10:48 a.m.	Hunt employee notified pipeline controller that Hunt pipeline was shut down and blocked off in area of release.
	10:49:51 a.m.	Clarke County Central Dispatch received call from pipeline controller reporting leak in Carmichael station area. Clarke County Central Dispatch told controller they were aware of event and had dispatched three fire and rescue units to the scene.
	10:52:37 a.m.	Pipeline controller closed remotely controlled suction and discharge valves at Carmichael and Butler Pump Stations.

Day	Time	Event
Thursday November 1	11:00 a.m.	Emergency responders decided to allow controlled burn of residual propane in pipeline.
Friday November 2	5:05 p.m.	Fire at pipeline self extinguished.
Sunday November 4	4:00 p.m.	Incident command concluded tactical on-scene activities.