# Collision of Norfolk Southern Freight Train 192 With Standing Norfolk Southern Local Train P22 With Subsequent Hazardous Materials Release at Graniteville, South Carolina
# January 6, 2005

## Railroad Accident Report

NTSB/RAR-05/04

PB2005-916304
Notation 7710A

National Transportation Safety Board
Washington, D.C.

**THE CORRECTIONS BELOW ARE *INCLUDED***
**IN THIS VERSION OF THE PUBLISHED REPORT**

RAILROAD ACCIDENT REPORT
NTSB/RAR-05/04 (PB2005-916304)

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GRANITEVILLE, SOUTH CAROLINA
JANUARY 6, 2005

- Page 50, fourth paragraph has been updated with the correct company name (Canadian Pacific Railway) instead of Canadian National as originally printed. (15 JUNE 2006)

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Adopted November 29, 2005

National Transportation Safety Board
490 L'Enfant Plaza, S.W.
Washington, D.C. 20594

**National Transportation Safety Board. 2005.** ***Collision of Norfolk Southern Freight Train 192 With Standing Norfolk Southern Local Train P22 With Subsequent Hazardous Materials Release at Graniteville, South Carolina, January 6, 2005.*** **Railroad Accident Report NTSB/RAR-05/04. Washington, DC.**

**Abstract:** About 2:39 a.m. eastern standard time on January 6, 2005, northbound Norfolk Southern Railway Company (NS) freight train 192, while traveling about 47 mph through Graniteville, South Carolina, encountered an improperly lined switch that diverted the train from the main line onto an industry track, where it struck an unoccupied, parked train (NS train P22). The collision derailed both locomotives and 16 of the 42 freight cars of train 192, as well as the locomotive and 1 of the 2 cars of train P22. Among the derailed cars from train 192 were three tank cars containing chlorine, one of which was breached, releasing chlorine gas. The train engineer and eight other people died as a result of chlorine gas inhalation. About 554 people complaining of respiratory difficulties were taken to local hospitals. Of these, 75 were admitted for treatment. Because of the chlorine release, about 5,400 people within a 1-mile radius of the derailment site were evacuated for several days. Total damages exceeded $6.9 million.

The safety issues addressed in the report are railroad accidents attributable to improperly lined switches and the vulnerability, under current operating practices, of railroad tank cars carrying hazardous materials.

As a result of its investigation of this accident, the Safety Board makes recommendations to the Federal Railroad Administration.

# Contents

# Executive Summary

About 2:39 a.m. eastern standard time on January 6, 2005, northbound Norfolk Southern Railway Company (NS) freight train 192, while traveling about 47 mph through Graniteville, South Carolina, encountered an improperly lined switch that diverted the train from the main line onto an industry track, where it struck an unoccupied, parked train (NS train P22). The collision derailed both locomotives and 16 of the 42 freight cars of train 192, as well as the locomotive and 1 of the 2 cars of train P22. Among the derailed cars from train 192 were three tank cars containing chlorine, one of which was breached, releasing chlorine gas. The train engineer and eight other people died as a result of chlorine gas inhalation. About 554 people complaining of respiratory difficulties were taken to local hospitals. Of these, 75 were admitted for treatment. Because of the chlorine release, about 5,400 people within a 1-mile radius of the derailment site were evacuated for several days. Total damages exceeded $6.9 million.

The National Transportation Safety Board determines that the probable cause of the January 6, 2005, collision and derailment of Norfolk Southern train 192 in Graniteville, South Carolina, was the failure of the crew of Norfolk Southern train P22 to return a main line switch to the normal position after the crew completed work at an industry track. Contributing to the failure was the absence of any feature or mechanism that would have reminded crewmembers of the switch position and thus would have prompted them to complete this final critical task before departing the work site. Contributing to the severity of the accident was the puncture of the ninth car in the train, a tank car containing chlorine, which resulted in the release of poisonous chlorine gas.

The safety issues identified in this investigation are as follows:

- Railroad accidents attributable to improperly lined switches;
- The vulnerability, under current operating practices, of railroad tank cars carrying hazardous materials.

As a result of its investigation of this accident, the National Transportation Safety Board makes safety recommendations to the Federal Railroad Administration.

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# Factual Information

## Accident Synopsis

About 2:39 a.m. eastern standard time on January 6, 2005, northbound Norfolk Southern Railway Company (NS) freight train 192, while traveling about 47 mph through Graniteville, South Carolina, encountered an improperly lined switch that diverted the train from the main line onto an industry track, where it struck an unoccupied, parked train (NS train P22). The collision derailed both locomotives and 16 of the 42 freight cars of train 192, as well as the locomotive and 1 of the 2 cars of train P22. Among the derailed cars from train 192 were three tank cars containing chlorine, one of which was breached, releasing chlorine gas. The train engineer and eight other persons died as a result of chlorine gas inhalation. About 554 people complaining of respiratory difficulties were taken to local hospitals. Of these, 75 were admitted for treatment. Because of the chlorine release, about 5,400 people within a 1-mile radius of the derailment site were evacuated for several days. Total damages exceeded $6.9 million.

## Site Description

Graniteville, South Carolina,[1] is an unincorporated community of about 1,200 (1990 data) in a mixed rural and suburban area of Aiken County. Graniteville is about 4.5 miles west of the commercial/retail district of the city of Aiken, South Carolina, and about 9.8 miles northeast of the commercial/retail district of Augusta, Georgia. (See figure 1.)

Principals of local emergency response agencies estimated that 5,400 people live within a 1-mile radius of the accident site; this includes peripheral areas of adjacent communities. The fire district of the local responding fire and rescue agency (the Graniteville, Vaucluse, and Warrenville Volunteer Fire Department) has an approximate population of 22,000, which includes communities adjacent to Graniteville that were not directly affected by the incident.

NS main line track runs in a north-south direction through the center of Graniteville. To the east of the main line and extending in a southerly direction is an area of primarily residential properties. To the west and extending in a northerly direction is an area comprising several moderate- to large-sized industrial plant facilities, some of which operate continuously. A small commercial/retail district is adjacent to and north of the main line right-of-way (about 1,000 feet from the accident site). Two principal north-south thoroughfares run parallel to and on either side of the NS main line. These thoroughfares are Canal Street[2] to the west and Trolley Line Road to the east.

[1] Local maps identify a location proximate to Graniteville as New Hope, but local residents consider the locality to be Graniteville.

[2] Canal Street is also known locally as Main Street.

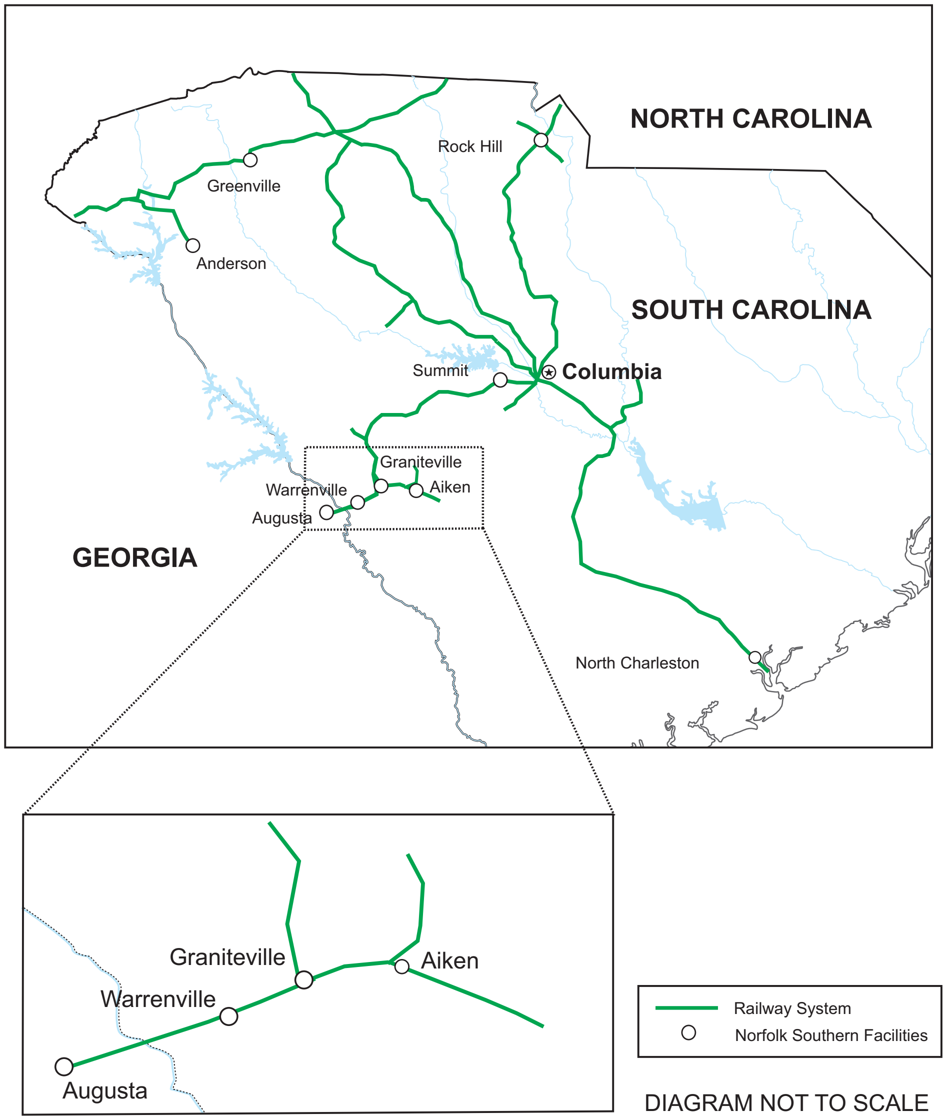


**Figure 1.** Accident location.

Graniteville lies in a shallow valley that encompasses a stream, known as Horse Creek, which is about 1,000 feet west of the NS main line and somewhat parallels it. The terrain adjacent to Horse Creek generally gains elevation as it extends to the east and to the west of the streambed. The Horse Creek streambed is about 190 feet above sea level. The main line track at the accident location is about 225 feet above sea level, with the terrain moderately increasing in elevation as the track extends toward the north. The industry track elevation is also about 225 feet at the turnout, with the elevation moderately decreasing as the track extends north and west toward the plant.

The industry track where the accident occurred serves facilities of Avondale Mills, Inc., a manufacturer of textiles. (See figure 2.) The facilities include the mill's Woodhead, Hickman, and Gregg Division plants as well as the Stevens steam plant. The Avondale Mills industry track (hereinafter referred to as "industry track"), upon diverging from the NS main line, immediately traverses Canal Street at a roadway at-grade crossing and continues in a northwesterly direction. The track then traverses Hickman Street at a roadway at-grade crossing before continuing in a northwesterly direction toward several industrial facilities and additional track turnouts. The portion of the industry track between the Canal Street grade crossing (edge of pavement) and the Hickman Street grade crossing (edge of pavement) measures about 328 feet in length.

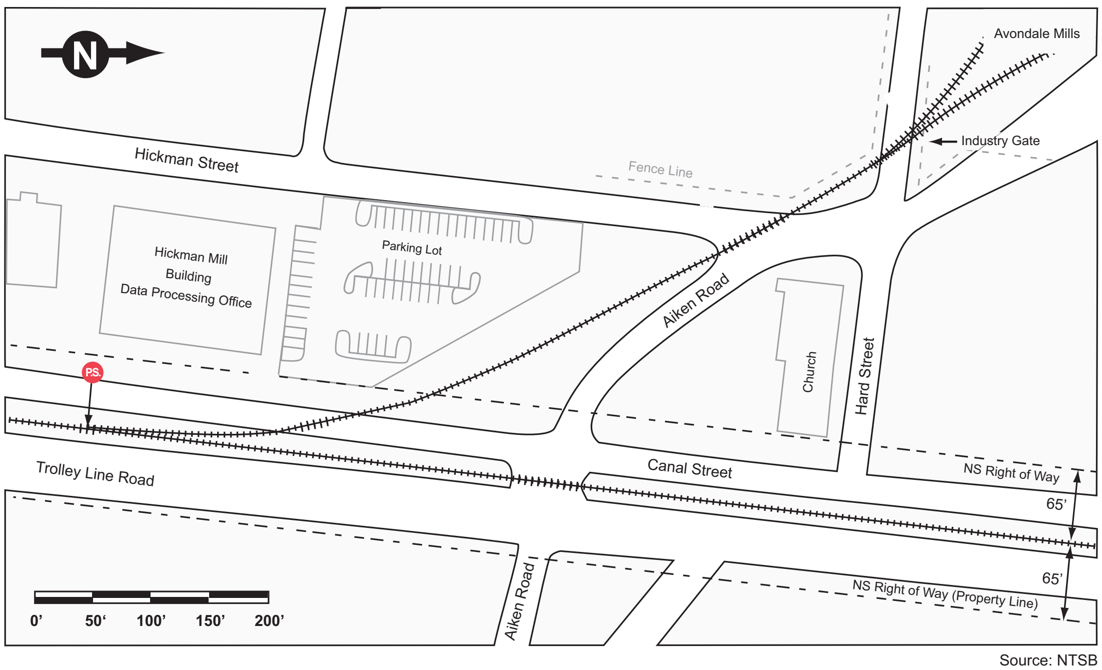


**Figure 2.** NS main line and Avondale Mills facility industry track in Graniteville. "P.S." identifies the point of switch from the main line onto the industry track.

## Events Preceding the Accident

NS local train P22 (full designation P22P005) operated Monday through Friday out of the NS yard at Aiken, South Carolina. The train crew (engineer, conductor, and brakeman) normally went on duty at 7:00 a.m. and spent the day placing and picking up cars at local industries along the main line.

On January 5, 2005, the day before the accident, the regularly assigned train P22 conductor was on vacation. During his absence, the train's regularly assigned brakeman was working as conductor, and the brakeman's job was filled from the extra board.[3] Both the conductor and brakeman went on duty in Aiken at 7:00 a.m. on January 5. The regularly assigned engineer for train P22 had taken the day off, and his job was also being

[3] The *extra board* is a list of qualified employees available to work in the absence of a regular employee or to work unscheduled assignments. At the time of the accident, temporary job vacancies on train P22 were filled from among extra board employees working out of Columbia, South Carolina, about 58 miles from Aiken.

filled from the extra board. Because of rest requirements,[4] the only available extra board engineer could not begin work until 8:32 a.m.

The NS trackage in this area is non-signaled, and authority to use various track segments is via track warrants issued by the train dispatcher in Greenville, South Carolina. At 8:11 a.m., the train P22 conductor was given a track warrant authorizing train P22 to occupy and work on the east-west main line (designated the SA line) between milepost (MP) SA51.0 and Warrenville, South Carolina (MP SA63.4). The SA main line connects Aiken with the north-south main line (designated the R line) on which the accident occurred. (See figure 3.)

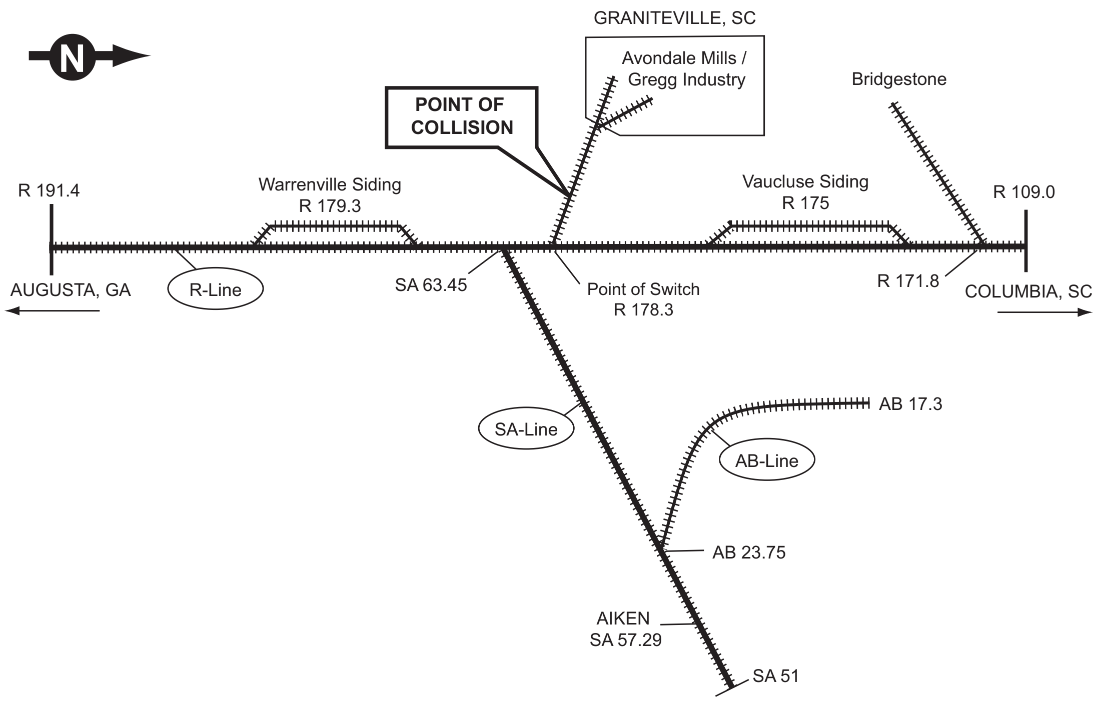


**Figure 3.** NS main lines in the accident area. Mileposts are referenced by letter and number designations.

The brakeman said that after the engineer arrived, the conductor held a job briefing with the crew in which he advised them of specific movements that were to be made during the shift.[5] After the briefing, the crew boarded its locomotive, coupled to eight freight cars, and departed the Aiken Yard.

[4] Required off-duty time between assignments, generally referred to as "rest," is governed by Federal regulations and union agreements.

[5] At the time of the accident, the Federal Railroad Administration had recommended, but had not required, that railroads mandate such job briefings. The NS *Safety and General Conduct Rules* required that job briefings be held "to review the planned itinerary, procedures, and necessary safeguards for the task to be performed." The rule specified that such a briefing "must always precede the task at the work site, be clearly understood, and be updated or modified as conditions change."

The crew spent the first part of the day servicing industries along the SA line before returning to the Aiken Yard about 1:00 p.m. for lunch. After lunch, the crew re-boarded the train, and about 2:10 p.m., the conductor received a second track warrant authorizing the train to occupy and operate on the R main line track between MP R185.0 and MP R171.0. Train P22 then proceeded east to the junction of the SA and R main lines.

During the afternoon, the crew worked various industries along the R line from Bath, South Carolina, (MP R185.0) north to the Bridgestone industrial lead (MP R171.8). The engineer said that about 4:00 p.m., the crewmembers realized that they would be "pressed for time" to complete their planned work. The crewmembers completed their duties at the Bridgestone lead at 5:50 p.m. After leaving Bridgestone, the crew intended to place two cars of sodium hydroxide solution (caustic soda) at the Avondale Mills plant at MP R178.3, after which they planned to proceed south to Warrenville (MP R179.3) and tie down the train for the night. The conductor had arranged with a taxi service under contract to the NS to have a taxi waiting at Warrenville at 6:15 p.m. to take the crew back to Aiken.

Train P22, now with 12 freight cars, reached the industry track about 6:10 p.m. According to the engineer, although the conductor and brakeman had conducted job briefings at other work sites during the day, no job briefing was held before the work began at the Avondale Mills plant. When he was later asked why he believed no job briefing was held, the engineer said, "It could have been they [the conductor and brakeman] were in a hurry."

The train stopped on the main track with its locomotive about 6 car lengths north of the main track switch for the industry track.[6] (See figure 4.) The conductor said that he told the brakeman to bring in the train on the industry track, after which the conductor dismounted the locomotive and walked west to open the facility gates and make sure the tracks were clear. (See figure 5.) The conductor also lined the industry track switches for the move. The train then pulled south, stopping just north of the switch, at which point the brakeman dismounted. The train pulled south again and stopped when the last car was clear of the industry track switch. The brakeman lined and locked the switch[7] (see figure 6) to allow the train to move from the main track onto the industry track, then walked back to flag the first road crossing. After the conductor had prepared the route, the engineer shoved the train from the main line onto the industry track. Once the train occupied the first crossing, the brakeman radioed the engineer to stop. The brakeman mounted the leading end of the last freight car, and the train shoved back again, with the conductor flagging the next road crossing.

[6] The information in this section regarding crew actions and train movements is based on postaccident interviews with the crewmembers.

[7] Main line switches have locks that deter tampering by unauthorized persons. Railroad employees have keys for the locks, and they are expected to relock a switch after it has been repositioned.

**Figure 4.** Looking north at the switch and turnout from the NS R main line onto the Avondale Mills industry track at Graniteville. The switch banner, or target, shows white, indicating that the switch is in the “normal” position, that is, aligned for movement along the main line track. (The banner shows red when the switch is set for the industry track.) North of the turnout and to the right of the main line is the wayside light indicating the position of the switch for the Vaucluse Siding.

**Figure 5.** The Avondale Mills industry track and gates to the Avondale Mills facility at Graniteville.

**Figure 6.** The switch stand for the Avondale Mills turnout switch at Graniteville showing the switch locked in position.

Train P22 had to pull out and set aside two empty cars before it could place the two loaded caustic soda cars at the facility. (According to the engineer, these moves did not require that the train pull out as far as the main line, and no part of the train moved over the main line switch after the train was backed onto the industry track.) The conductor said that he was aware that the Federal hours-of-service limitation of 12 on-duty hours[8] would occur for himself and the brakeman at 7:00 p.m., and he told the engineer and the brakeman that they would not have time to continue to Warrenville as planned. At 6:20 p.m., he radioed the taxi driver waiting at Warrenville and told him to come to the industry track (about 1 mile north of Warrenville) to pick up the crew.[9]

After placing the two caustic soda cars at the Avondale Mills plant, the crew prepared to leave the train on the industry track for the night. Because of the length of the train and the need to avoid blocking the road crossings or the plant gate, the crew had to uncouple 8 cars from the 10-car train and place them on two tracks within the plant gates. The engineer then moved the locomotive and the remaining two empty freight cars onto the industry track between the main line and the industry gate, stopping the locomotive in the clear about 5 to 6 car lengths from the main line switch.[10] About this time, the taxi arrived and parked on the grass on the east side of the industry track near the locomotive.

[8] Title 49 *Code of Federal Regulations* Part 228.

[9] The vehicles used by the contracted taxi service have radios that allow them to communicate with train crews.

[10] The length of train P22 as parked on the siding was about 172 feet. Based on this measurement, crew statements, and other documentation obtained during the investigation, the head end of train P22 was estimated to be about 342 feet from the switch stand for the main line track switch.

The engineer applied the locomotive handbrake and began shutting down and securing the locomotive. The brakeman said that he closed one of the two sides of the swinging gate at the entrance to the plant and walked toward the locomotive to tie down the train and retrieve his personal belongings. He said they had been "pushed for the [hours-of-service] law" as they worked, and he noted the time and was "in a hurry to get everything done that I needed to do." The brakeman said he looked at his watch and noted that it was about 6:59 p.m. when he reached the locomotive. The brakeman set handbrakes on the train and retrieved his bag from the locomotive.

Meanwhile, the conductor noted that it was about 6:57 p.m. when he closed the other side of the plant gate and began walking toward the locomotive. He said he remembered thinking to himself, "Lord, mission accomplished. Everybody's happy. Let's get our stuff and go in." He said he saw the brakeman at the locomotive when he arrived. He said he retrieved his clipboard and bag and placed them in the back of the taxi, then went back to help the engineer with his bag. The three crewmembers then got in the taxi, and the taxi departed.

During the time the crew was working at the Avondale Mills facility, the main line switch remained lined for the industry track. NS Operating Rule 104, in effect at the time, required that the train P22 crew return the switch to its "normal" position (lined and locked for the main line) when the work was complete. Rule 104(a) states that, while the position of a switch is the responsibility of the employee handling it, "this…does not relieve other crewmembers of the responsibility if they are in place to observe the position of switches."

In postaccident interviews, the brakeman said he was aware that whenever a job is completed, any main line switch that was used must be lined and locked for the main track. He said,

> in my mind, when I left [the industry track], everything was properly lined back to the main line. I had no doubts in my mind when I left there.

He also said, "I am not 100 percent sure that I did [reline the main line switch]. I would say I might have made a mistake."

The engineer said that he was on the "off side" of the locomotive and could not see the main line switch while working on the industry track. He said that he did not know "how the brakeman handled it."

The conductor stated:

> While we [were] working in the plant, I was off in the field and I never got near the switch…. We usually have job briefings, but I never told my brakeman to make sure that the switch was lined and locked for the main line movement. I never told him, and I never touched the switch myself. It was in my mind when I arrived at the mill. I should have done a briefing to ensure that the switch was lined back.

The conductor also stated that because the industry track was curved, the main line switch banner[11] was not illuminated by the locomotive headlight while the train was in the industry track, nor was it otherwise visible to the crewmembers while they worked.

The conductor said he had no conversations with the engineer or the brakeman about the way the switch was lined. The conductor also said, and the taxi driver confirmed, that the subject of the switch did not come up during the ride back to the terminal. The conductor said, "Once we got in that taxi, we went back toward the depot; and in my mind, everything was all right." As it left the area, the taxi traveled south along Canal Street and over a grade crossing within 21 feet of the main track switch, but neither the driver nor his passengers noted its position.

The taxi arrived at the Aiken Yard office at 7:15 p.m. After the crewmembers gathered their belongings, the engineer departed the yard while the conductor and brakeman proceeded to the yard office. About 7:50 p.m., as the conductor was completing his paperwork, he asked the brakeman to contact the train dispatcher and clear the two track warrants that had been issued to train P22. The brakeman cleared the two track warrants with the dispatcher at 7:53 and 7:54 p.m., respectively. The brakeman said later that he would not have cleared the track warrants for the conductor if he had thought he had not left everything lined properly at the industry track.[12] The conductor and brakeman completed the paperwork at 8:11 p.m.[13]

## The Accident

The train dispatcher on duty when local train P22 finished its work said that no trains occupied the main line track in the Graniteville area from the time the local's track warrants were cleared at 7:54 p.m. until he went off duty at 11:00 p.m. The dispatcher who came on duty at 11:00 p.m. said that he gave no authority for train operations over that section of track until after 2:00 a.m. on January 6, 2005, when he issued a track warrant for NS freight train 192 (full designation 192P005) to operate from Augusta, Georgia (MP R191.4), to Summit, South Carolina (MP R132.8).

Train 192 originated in Macon, Georgia, on January 5, 2005, and was destined for Columbia, South Carolina. The NS records indicate that the train received an initial terminal air brake test in Macon at 10:50 a.m. The train departed Macon at 1:30 p.m. on January 5 with 2 locomotives, 16 loads, and 14 empties.

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[11] A switch *banner*, sometimes termed a switch *indicator* or switch *target*, is typically a reflectorized metal flag-like device connected to the switch stand. (See figure 4.) It consists of one or two flags of different colors that indicate the position of the switch.

[12] NS Operating Rule 181, regarding track warrants, states, in part, "When clearing [a track warrant] at a point where a switch must be returned to the normal [main line] position, 'clear' must not be given until such switch has been locked in the normal position…."

[13] Although the crew completed train operations within the 12-hour Federal hours-of-service limit, the time required to complete paperwork for the train caused the on-duty time of the conductor and brakeman to exceed 12 hours. The NS subsequently filed excess service reports with the Federal Railroad Administration for this time.

While en route, the head-end train telemetry device on the lead locomotive failed to communicate properly with the end-of-train telemetry device.[14] At McBeam, Georgia, the train crew switched the two locomotives, after which reliable communications were established. No other problems were encountered en route. The train arrived at 10:50 p.m. at the NS Nixon Yard in Augusta, Georgia, where the inbound crew went off duty.

The outbound train 192 crew (engineer and conductor), who would continue the trip toward Columbia, South Carolina, went on duty at 12:30 a.m. on January 6, at Nixon Yard. The conductor said that after taking control of train 192 at Nixon Yard and receiving the necessary track warrant, he and the engineer took the train about 4 miles across town to the NS Augusta Yard, where they performed switching duties and added cars to the consist. After a successful brake test, train 192 departed Augusta Yard about 2:10 a.m. on January 6. The train consisted of two locomotive units (operating short hood forward) pulling 25 loads and 17 empties. The train had a trailing tonnage of 3,520 tons and a length of 2,553 feet. The NS consist list for the train showed 14 cars containing hazardous materials or hazardous materials residue.[15]

About 30 minutes and 13 miles after departing Augusta, train 192 approached the industry track at Graniteville. According to event recorder data, the train was traveling 44 mph at this time (recorder time 2:36:30 a.m.). The engineer moved the throttle handle to notch 8 (maximum throttle), and the throttle remained in this position until 2:38:11, when the train speed indicated 47 mph. As the speed continued to increase to 48 mph, the engineer decreased the throttle to notch 6. At recorder time 02:38:37, the throttle handle was placed in notch 4, with the speed remaining at 48 mph.

The conductor stated that about this time he heard the train's emergency brakes activate. He said he recalled the engineer saying, "The target [switch banner] is wrong,"[16] but the conductor said he did not observe the switch target himself. He said that his train was diverted onto the industry track, where it struck another train, throwing him to the floor of the locomotive. He said he recalled smelling chemicals after the impact. Event recorder data indicated that the speed of the train at 2:39:00 a.m., approximately 467 feet from the final resting point, was 47 mph. At 2:39:20, the speed registered 0 mph.

According to dispatcher radio transcripts, at 2:40:11 a.m., a radio emergency tone sounded at the desk of the NS dispatcher on duty in Greenville. When the dispatcher responded to the emergency tone, a caller (believed by the dispatcher to be the train 192 engineer) reported:

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[14] The end-of-train telemetry device (EOTD) transmits pertinent information, including brake pipe pressure at the rear of the train, to the head-end telemetry device (HOTD) on the lead locomotive.

[15] These included three tank cars of chlorine (the 6th, 7th, and 9th cars from the locomotives); two tank cars of sodium hydroxide (the 8th and 31st cars); two tank cars containing residue of elevated temperature rosin (the 16th and 17th cars); one tank car of cresols (the 18th car); four tank cars containing methanol residue (the 24th through 27th cars); and two tank cars of aniline (the 34th and 35th cars).

[16] The investigation revealed that the switch target was on the engineer's side (the west side) of the locomotive as the train proceeded north.

> Dispatcher, this is train…192…. We need emergency assistance in Graniteville. We just…hit a switch…at Graniteville…. It was lined off the main line and we went around there and…hit an engine that was in the track. …We went through the switch at 45 mph. We need help.

Asked by the dispatcher if the crew was all right, the caller said, "It just happened…. We need an ambulance. I think I'm bleeding."

According to NS records, the dispatcher reported the collision and possible injury to the NS police command center. An employee of the command center subsequently reported the accident to the Aiken County Sheriff's Department and requested emergency medical services.

In a Safety Board interview, the conductor said that he attempted to get off the locomotive from his side (the east side) of the locomotive, but was unable to do so because the window and door were jammed. He said that he exited the locomotive from the other side, followed by the engineer. The conductor said that he and the engineer then walked about 100 yards, at which point they "met up with some people." He recalled the engineer saying that they needed to get "downwind" of the area. He also recalled seeing white or gray smoke, but no fire. He said they walked a little farther, and then lay on the ground.[17]

## Emergency Response

When train 192 struck train P22, both locomotives and the first 16 cars of train 192 derailed. (See figure 7.) The ninth car from the locomotive units, containing 90 tons of chlorine, was punctured during the derailment and released chlorine gas. Winds were light at the time of the accident, and the chlorine vapor cloud settled in the low-lying valley along the tracks.[18] Based on emergency responder observations and the locations of those receiving fatal injuries, the cloud extended at least 2,500 feet to the north; 1,000 feet to the east; 900 feet to the south; and 1,000 feet to the west. The sudden release and expansion of the escaping gas caused the product remaining in the tank to auto-refrigerate and remain in the liquid state, slowing the release of additional gas.

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[17] The conductor said that he was subsequently informed in a hospital that an Avondale Mills employee placed him on the back of his truck and transported him to a hospital after he and the engineer walked away from the collision. A motorist reported picking up the engineer and transporting him to a hospital.

[18] Because chlorine gas is heavier than air with a vapor density of 2.5 at 32° F, it will seek the lowest point in the immediate area.

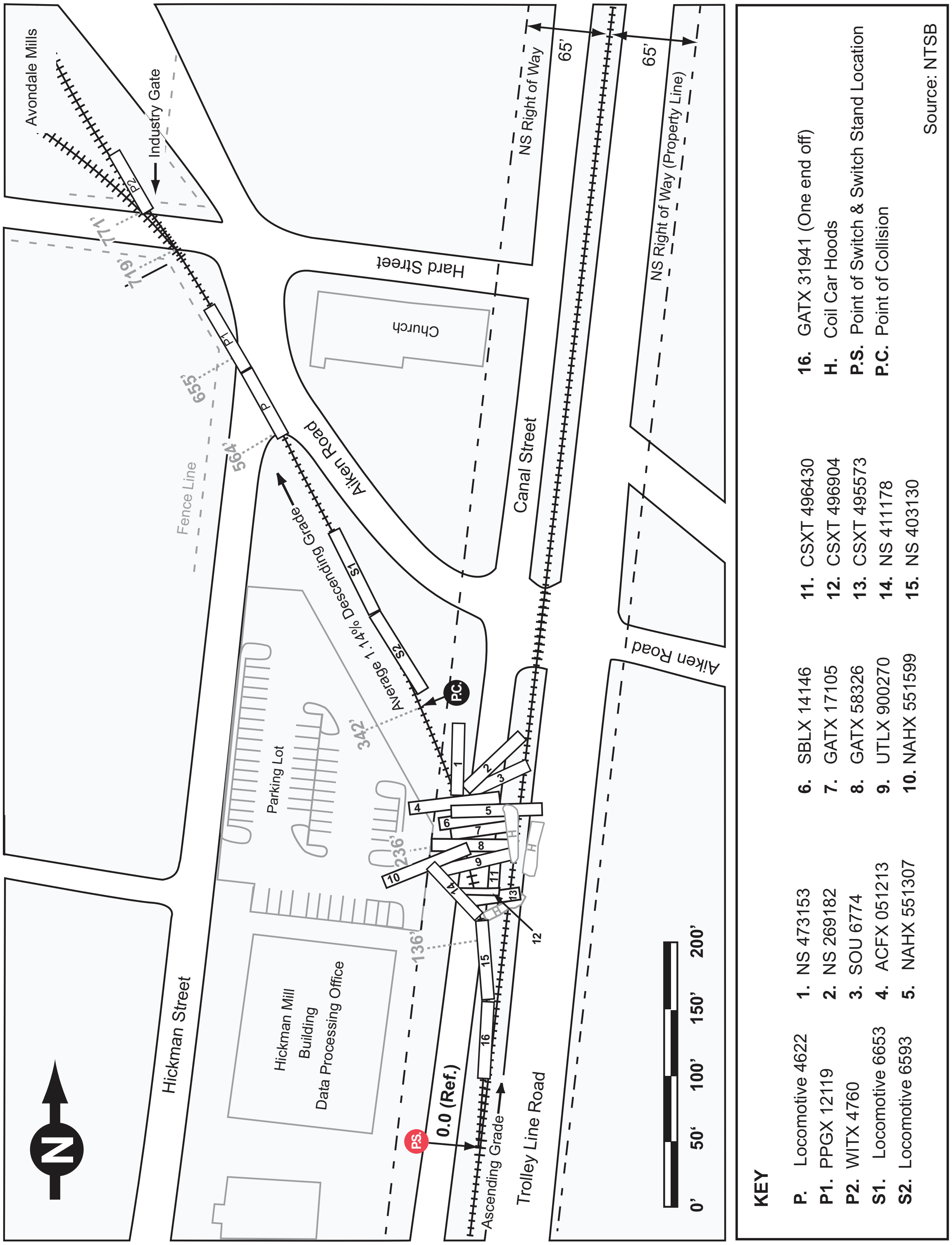


**Figure 7.** Distribution of wreckage after the derailment and collision. "P.C." indicates estimated point of collision

Immediately after the collision, at 2:39:43 a.m. on January 6, a female employee on duty at one of the Avondale Mills facilities (about 200 feet from the collision site) placed a 911 call to the Aiken County Sheriff's Office 911 Emergency Call Center. The caller identified herself and reported, "I think there's been a train wreck…at Graniteville…at Hickman Mills." She said that she was alone and that when she went outside to investigate, she could "see smoke" but could not discern exactly what had happened. She further indicated that the accident was at the Hickman Street railroad grade crossing. Near the end of the 48-second call, the caller appeared to become increasingly agitated, saying, "I smell smoke." The caller then exclaimed, "I got to get out of here," at which point the call abruptly ended.

Over the next 10 minutes, about a dozen additional calls were made to 911, with callers reporting that there had been a train wreck. Some callers reported a low-lying yellow haze that smelled like bleach. Within about an hour after the accident, more than 100 additional 911 calls were received. By 6:00 a.m., more than 200 calls had been received. Also commencing about 2:40 a.m. were calls on the non-emergency telephone lines of the emergency call center. About 80 calls were received on these lines within the first hour, and by 5:40 a.m., about 200 calls had been received.

### *Fire Department Response*

At 2:40:40 a.m., resources of the Graniteville, Vaucluse, and Warrenville Volunteer Fire Department were dispatched to the scene, with the first responding unit reported to be en route less than a minute later.[19] At 2:42 a.m., upon hearing a report from the dispatcher that a smell of chemicals was reported in the area, the initially responding fire department senior officer (the fire chief) advised further responding fire department personnel to stand by at their locations away from the scene until the situation could be further assessed.

At 2:45 a.m., emergency dispatch advised the fire department that it had confirmed the possibility that two trains had collided head on. Additional confirmation came from the NS about 3 minutes later. The fire chief, upon approaching the scene, smelled an intense chemical odor and experienced difficulty breathing. At 2:46 a.m., a hazardous materials team was requested. At 2:48 a.m., the fire chief advised dispatch that he could not breathe and was withdrawing from the area. At 2:49 a.m., the fire department asked dispatch to initiate the Aiken County Reverse 911 Emergency Notification System, with instructions for residents to shelter indoors.

Commencing about 2:50 a.m., additional resources—ambulances, hazardous materials personnel and equipment, Aiken city and other mutual aid services—were asked to respond. At 2:52 a.m., dispatch advised responders that three persons were trapped inside the Hickman plant. At 2:54 a.m., fire department personnel asked dispatch to advise Aiken Hospital that persons overcome by chemical fumes were en route from the scene. At 2:57 a.m., the fire department asked that approach roads be blocked (which effectively initiated a 1-mile-radius buffer around the accident site) and reiterated the earlier reverse 911 request to shelter indoors.

[19] Information in this section is based on incident response data and communications information provided by the responding agencies, as well as on interviews with key emergency response personnel.

At 3:05 a.m., while awaiting delivery of train consist information that had been faxed from NS, the fire chief directed that an incident command center be established; the fire chief would become incident commander for the search and rescue effort. About this time, firefighters also asked dispatch to obtain wind direction information (from Bush Field in Augusta), which was received about 3 minutes later.

At 3:06 a.m., firefighters were informed that the sixth through ninth cars on the train contained chlorine and sodium hydroxide and that additional information would be forthcoming. At 3:08 a.m., the fire department began staging equipment and personnel at the incident command center, which had been set up at a nearby car dealership. At 3:10 a.m., firefighters asked that all Aiken County emergency medical services ambulances be placed on standby.

At 3:13 a.m., an Avondale Mills employee told firefighters that workers on duty at the Stevens steam plant could not be contacted. The employee expressed concern about a possible explosion if the workers had departed the plant without properly shutting down the boilers.

At 3:21 a.m., personnel from the Aiken County hazardous materials team arrived at the incident command center. At 3:24 a.m., a copy of the faxed train 192 consist list was delivered, and fire department authorities advised all responding personnel to report with their equipment to the command center. At 3:30 a.m., the fire department requested all available self-contained breathing apparatus.

At 3:33 a.m., a report was received of a "steady stream" of individuals departing the Ascauga Lake Road area. At 3:35 a.m., authorities established the first of four decontamination stations to treat individuals exposed to the chlorine gas. At 3:37 a.m., dispatch advised firefighters that it had received reports of people "down" inside the Avondale Mills facility. At the same time, a firefighter and a mill supervisor entered the steam plant to prevent a possible boiler explosion. A decision was made to shut down and evacuate the plant.

At 3:38 a.m., a second decontamination station was set up. At 3:39 a.m., the incident commander, concerned that the incident command center was too close to the accident site, directed that it be moved from the car dealership to a location about a mile away. Some emergency response apparatus remained at the initial site as a "forward command" location. At 3:40 a.m., a firefighter wearing personal protective equipment got close enough to the accident site to note the number on the tank car that had been breached. He also encountered an individual suffering from gas inhalation and discovered another individual trapped in an automobile beneath a fallen tree near the derailment site. (Both these individuals were later successfully rescued.)

Beginning at about 3:50 a.m., several entry teams, consisting of firefighters wearing personal protective equipment and riding in privately owned pickup trucks, were organized and dispatched to the accident site for search and rescue operations. Upon locating individuals or groups affected by the chlorine gas, the teams transported them to one of the decontamination sites. The entry teams then returned to the site to repeat the search and rescue cycle for several hours.

At 3:53 a.m., a third decontamination station was established at a local high school. At 4:10 a.m., an entry team reported a downed electrical power line near the wreckage site, and a request was made to the utility company to respond to the scene to disconnect the power feed. Also at 4:10 a.m., an entry team reported no visible fire in the derailment wreckage. This report was revised at 4:24 a.m., when responders reported seeing "bright orange smoke"[20] emanating from one railcar and "green smoke"[21] from another.

At 4:55 a.m., an entry team entered the steam plant to shut down the facility. Moments later, the mission was revised when "five or six" individuals were reported to be trapped in a room at the plant. One person was found and rescued, after which the team completed the shutdown of the steam plant at 5:07 a.m. and performed a final sweep of the plant. Several additional entry teams began missions to assess the condition of the railroad equipment.

The immediate area around the accident site remained relatively stable until 1:00 p.m., when a fire was reported at the steam plant. A fire department entry team entered the plant and found that a fire had ignited in coal chutes feeding several of the boilers. A pumper truck supplied water to an unmanned waterline-fed monitor nozzle that discharged a spray on all the coal feeders. At this point, the fire was under control but not extinguished. The discharging monitor nozzles were left in place while workers evacuated the area. The scene remained relatively stable for the balance of the day.

For the next several days, fire department entry teams monitored and contained the fire in the steam plant coal feeders while a cleanup of the railroad wreckage continued. At 8:00 a.m. on January 14, with the report that the hazardous materials had been removed from the unbreached railcars, support operations were concluded, and hazardous materials response personnel were released. At about noon, fire department personnel returned to the steam plant to extinguish the remaining fire in the coal feeders. The fire was reported extinguished at about 4:00 p.m., which concluded the fire department's operations for the incident.

### *Sheriff's Office Response*

After the initial 911 call, patrol units of the Aiken County Sheriff's Office were dispatched to the scene. The first sheriff's office responder arrived on the scene about 2:42 a.m., followed shortly thereafter by several other officers. When they approached the scene, the officers began experiencing respiratory difficulties because of the chlorine gas. They immediately withdrew to a safe distance and awaited further instruction. Several of the responding officers were taken to a local medical facility for treatment.

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[20] According to technical experts, the appearance of "orange smoke" is consistent with entrained ferric chloride in the released liquid chlorine. Light appears red as it passes through the ferric chloride that forms as chlorine reacts with steel in an oxygen-deprived environment. The absence of fire damage in proximity to the chlorine tank puncture indicates that the derailment did not result in a fire.

[21] The appearance of "green smoke" is consistent with a discharge of chlorine gas.

Workers and residents in the immediate vicinity of the gas release began to evacuate the area within moments of the accident. They were assisted in this evacuation by fire department and sheriff's office personnel on scene.

Later in the morning, the sheriff's office directed the evacuation of those who had been sheltering in place within a 1-mile radius of the site. This mandatory evacuation affected about 5,400 people. Sheriff's office personnel, assisted by mutual aid from a number of other area law enforcement agencies, conducted a house-to-house evacuation. Approach roads were closed at key intersections. The sheriff's office also instituted a 300-meter buffer zone around the site and restricted access to only those individuals wearing the appropriate personal protective equipment. The evacuation was lifted in phases, beginning on January 13, with the last evacuees permitted to return to their homes on January 19.

### *Hazardous Materials Response*

About 11:00 p.m. on January 6, responders inserted a temporary polymer patch in the opening of the punctured ninth tank car. At 7:00 p.m. on January 8, responders began unloading sodium hydroxide from the eighth tank car. At 8:50 p.m., the temporary polymer patch in the ninth tank car failed, releasing chlorine vapors and causing the unloading of the eighth tank car to be temporarily discontinued. By 8:37 a.m. on January 9, responders had inserted a second polymer patch in the opening in the punctured ninth tank car. Chlorine vapor was then drawn from the car to create a vacuum that would reduce the amount of chlorine gas escaping. The chlorine vapor removed from the tank was transferred into a sodium hydroxide solution to neutralize it. Following these measures, the unloading of the eighth tank car was resumed and completed by 3:30 p.m. While the eighth car was being unloaded, construction began on a permanent lead patch for the punctured ninth car.

At 9:30 a.m. on January 10, the punctured chlorine tank car was rotated so the puncture was at the highest elevation on the tank car. This rotation disturbed the liquid chlorine in the tank and caused a delay in efforts to unload other tank cars.

At 12:10 p.m. on January 10, responders began unloading the chlorine from the derailed sixth car in the train. On the morning of January 11, responders rejected the plan for a lead patch on the punctured ninth tank car and decided to use a steel patch instead. Unloading of the sixth car was completed by 2:00 p.m. on January 11.

About 1:10 a.m. on January 12, responders began unloading chlorine from the derailed seventh car. By 9:30 a.m., the steel patch was in place on the punctured tank car, and the unloading was started. Because the punctured tank car had extensive damage, the remaining chlorine could not be removed as it had been from the unbreached cars. The chlorine in this car had to be vaporized and transferred from the tank as a gas, after which it was bubbled through a sodium hydroxide solution held in a separate tank. This process, which converted the chlorine into a relatively safe and easily transportable liquid bleach and salt solution, required several days to complete.

By 2:10 p.m. on January 12, the unloading of the seventh car was complete. By the early morning hours of January 13, the two unbreached chlorine tank cars had been unloaded, placed on railroad flat cars, and moved from the site.

By midnight on January 18, the unloading of the punctured tank car was complete. (See figure 8.) On January 19, by 9:00 a.m., the tank car was cleaned and purged on site. It was then loaded on a flat car and moved to the Augusta Yard the following morning, January 20.


**Figure 8.** Ruptured chlorine tank car during unloading. The tank has been rotated so that the patched puncture is at the top. Hoses attached to the patch are drawing off chlorine vapors that are then bubbled through a sodium hydroxide solution to reduce their hazard.

## Injuries

Nine persons, including the train 192 engineer, died from chlorine gas inhalation as a result of the accident.[22] Of the eight civilians who received fatal injuries, six were employees of Avondale Mills facilities to the west and north of the accident site, one was a truckdriver at one of the plant facilities to the west of the site, and one was in a residence south of the site.

[22] The death of another Graniteville resident on April 19, 2005, was initially reported by media sources to have occurred as a result of exposure to the chlorine gas released in the accident. The final autopsy report for this individual listed the death as natural due to pulmonary thromboemboli. Regardless of the circumstances, this death would not have met the criteria for death reporting under 49 *Code of Federal Regulations* 830.2, because it did not occur within 30 days of the accident.

About 554 people, among them civilians, railroad crew, and emergency responders, were taken to local hospitals complaining of respiratory difficulties. Of these, 75 were admitted for treatment. Six firefighters were treated and released; one firefighter was admitted to the hospital and remained there for several days. Two sheriff's department officers were also treated and released.

The coroner's investigation reports for the eight deceased civilians all listed the probable cause and mechanism of death as asphyxia, which occurred within "minutes" of exposure, with secondary/contributing factors that included exposure to chlorine gas. The locomotive engineer survived the collision but died several hours later. The coroner's investigation report listed the probable cause and mechanism of death of the engineer as lactic acidosis with secondary/contributing factors that included exposure to chlorine gas.

## Damages

### *Hazardous Materials Cars*

Of the 16 derailed cars, 5 contained hazardous materials or hazardous materials residue. The hazardous materials cars included three tank car loads of chlorine (the 6th, 7th, and 9th cars from the locomotives), one tank car load of sodium hydroxide (the 8th car), and one empty tank car containing residue of elevated temperature rosin (the 16th car). The ninth car was the only derailed hazardous materials tank car that was breached and released its cargo. The other four tank cars were damaged, but their tanks were not breached.

The sixth car (chlorine) sustained a severe dent just to the right of center in the lower half of the B-end head. The appearance and location of the dent was consistent with its having been made by a coupler from another car. The bottom of the tank sustained some flattening, and the jacket was substantially damaged.

The seventh car (chlorine) sustained a severe dent on the left side (from the B-end) between the center of the tank and the A-end, just below the midline of the tank. A severe dent was also found on the A-end to the left of the coupler, and the coupler had been torn out. The jacket had several dents, with the most severe occurring between the B-end and the top fittings.

The eighth car (sodium hydroxide) sustained extensive jacket damage, and the jacket was torn from almost one-third of the tank on the A-end. Two smaller dents were observed in the shell near the A-end on the right side (from the B-end). The coupler and draft gear were missing from the B-end, and the stub sill was bent upwards.

The ninth car (chlorine) had a puncture and a tear on the right side near the middle and slightly toward the A-end of the tank. The opening was 34 inches long and 5 inches wide at its widest point. The area around the puncture was crushed inward, and there were severe dents on either side of it. These dents ranged in depth from 15 to more than 20 inches. The car came to rest angled slightly to one side with the puncture opening extending below the midline of the resting tank. The left side of the tank had some flattening, and there was a dent on the shell near the A-end head weld at about the 2 o'clock position. Emergency responders on the day of the accident measured the liquid level of the chlorine remaining in the tank and found that about one-third of the original load, or 30 tons (4,609 gallons), remained in the tank.[23] The responders also noted that the B-end coupler[24] of a steel coil car (the 11th car in the train) was in contact with the damaged tank jacket near the puncture and that it had frost on its surface. Metallurgical examination of the puncture area revealed that the dents in the puncture area mated with damaged protrusions on the 11th-car coupler.

### *Other Railroad Equipment*

The lead locomotive unit of train 192 derailed but remained upright (leaning to the east at about a 12° angle) and positioned somewhat aligned with and about 4 feet from the centerline of the industry track. (See figure 9.) The locomotive unit appeared not to have lost overall structural integrity or to have sustained significant loss of occupant survival space. The cab windows were not broken. The unit sustained severe impact damage to the front end, with the front coupler, pilot plate structure, and stepwell elements severely mangled and with various components bent and displaced in an upward and aft direction by about 2 feet. Except for the front impact damage, the carbody of this unit did not exhibit substantial collision damage.


**Figure 9.** The lead locomotive of train 192 (left) and the lead locomotive of train P22 (right) showing collision damage.

[23] The NS estimated the amount remaining in the tank at 44 tons, or about 1/2 the original load of 90 tons.

[24] A standard E-type bottom-shelf coupler.

The second locomotive unit on train 192 derailed but remained coupled to the lead locomotive, upright and positioned with the aft end skewed from alignment with the track by about 15 feet. The unit showed impact damage at the aft end on the right side of the frame, including a segment of missing handrail. The aft right corner pilot plate structure and stepwell elements were severely bent and displaced in an aft direction. The aft left corner pilot plate structure sustained impact damage. Except for the aft end frame and pilot plate structure damage and several carbody panel separations, this unit did not show substantial collision damage. There was visible evidence of a diesel fuel spill beneath the fuel tank, but there was no apparent fire.

Train P22 consisted of one locomotive and two empty freight cars at the time of the accident. It was propelled about 217 feet northward (along the track) by the impact. The locomotive derailed but came to rest upright and positioned somewhat longitudinally aligned with the track about 3 feet to the east of the track centerline. The unit sustained impact damage to the front end, with the front coupler, pilot plate structure, and stepwell elements severely mangled. Various components were bent and displaced in an upward and aft direction by about 5 feet.

The P22 locomotive unit sustained severe impact damage to the front carbody cowl (short hood), which was displaced in an aft direction by about 2 feet. The right side-sill was buckled downward several inches, proximate to the area above the fuel tank. The left side-sill was also buckled, but to a lesser degree than the right. Except for the front impact damage and the damaged side-sills, the carbody of this unit did not exhibit substantial collision damage. There was visible evidence of a diesel fuel spill beneath the fuel tank but no evidence of fire. The cab compartment appeared to be relatively intact and did not lose overall structural integrity or sustain significant loss of survival space. One window on the left side of the cab was shattered.

The first railcar on train P22 was a covered hopper. It did not derail and remained coupled to the locomotive. The second railcar, also a covered hopper, uncoupled from the first car and came to rest about 81 feet away along the industry track. Both truck assemblies separated from the carbody. The leading truck assembly was found on the ground adjacent to the car's front coupler; the aft assembly was found wedged against the underside discharge door beneath the center of the car. The leading end of the car was on the ground; the aft end had overridden and was wedged against and resting upon the leading end-sill of a tank car that had been on the industry track west of train P22.

Some main line and industry track was damaged in the derailment or removed to facilitate cleanup. A total of 14 track panels (39 feet each) were installed: 6 panels on the main track and 8 panels on the industry track. In addition, 10 carloads of ballast stone were spread. Total damage to the rolling stock and track was estimated in excess of $2.19 million. The NS reported total damages to exceed $6.9 million.

### *Emergency Response Equipment*

The Graniteville, Vaucluse, and Warrenville Volunteer Fire Department reported that two pumper trucks, one medical unit vehicle, and one service truck, all of which had been parked at the department's Station No. 1 for the duration of the gas release, had been destroyed or damaged beyond economical repair as a result of chlorine gas contamination. Total cost for the damaged or destroyed equipment was estimated in excess of $630,000.

## Wreckage

Wreckage and debris of the derailed railroad equipment extended more than 500 feet, beginning at the industrial turnout switch and continuing in a northerly direction along the industry track. Investigators were not able to perform a detailed documentation of the wreckage because of the continuing potential of a hazardous gas release and because of the wreckage cleanup efforts that prevented access to the site.

## Personnel Information

### *Train P22*

**Engineer.** The train P22 engineer was originally hired on July 25, 1979, as a car retarder operator.[25] On September 3, 1979, he was promoted to yard foreman, helper, and trainman. On July 7, 1986, he was promoted to conductor. He became an engineer on September 12, 1990. His most recent engineer re-certification was on August 16, 2004.[26]

The engineer stated that he was not preoccupied or distracted during his shift. He also said he was not aware that either his brakeman or conductor was preoccupied or distracted during their shift. He said that other than intermittent problems with his locomotive radio, he experienced no problems with any of his equipment.

The engineer characterized his health as good. His most recent physical examination before the accident was in August 2004. The engineer explained that he underwent two physicals at that time: one conducted by his personal physician and one as part of his engineer re-certification. He said that he had no problem with his hearing or vision, although he wore prescription reading glasses. He said he had not used any over-the-counter or prescription medications, but said he periodically took vitamins. He also said he had not used alcohol or illicit drugs on the day before the accident.

As an extra-board employee, the engineer was called to work as needed. He said he was called at 1:00 a.m. on Tuesday, January 4, for a 2:30 a.m. on-duty time. He worked from that time until about 12:30 p.m. on January 4. He said he went to bed about 7:00 p.m. on January 4. At 10:32 p.m., the engineer was called to work as the engineer on train P22 the next day, January 5. He was authorized to deadhead (by taxi or other means) from his

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[25] A *car retarder operator* remotely operates a brake device built into the rails to reduce the speed of cars being switched into a classification yard (where cars are grouped before being made up into trains).

[26] Engineer certifications are valid for 3 years at time of issuance and include an evaluation of vision and hearing.

home in Columbia to Aiken to arrive at 12:32 a.m. so that he would be in place and ready for work the next morning. Because the engineer was required to be given 8 hours rest time after arriving in Aiken, he could not report for train P22 until 8:32 a.m., more than 1 1/2 hours after the conductor and brakeman had gone on duty.[27] He went off duty at 8:11 p.m. and had been off duty for about 6 1/2 hours when the accident occurred.

**Conductor.** The train P22 conductor (who was the regularly assigned P22 brakeman but who was working in place of the vacationing conductor on the day before the accident) was originally hired as a trainman on April 4, 1978. On May 18, 1978, he was promoted to yard foreman, helper, and trainman. On January 2, 1992, he was promoted to conductor.

The conductor said he had no problems with any equipment as he worked the day before the accident. Similarly, he had experienced no problems related to the weather, nor was he distracted or preoccupied while he performed his duties. He stated his overall health was "in good shape." He said he had not used prescription medications but that he sometimes took medicine for allergies. The conductor said that he believed he had taken two Benadryl[28] tablets about 1:00 p.m. on the day before the accident. He said he took no additional over-the-counter medications, nor did he consume any illicit drugs or alcohol that day. The conductor recalled that his most recent physical examination before the accident was in January or February 2004, adding that he undergoes a physical examination annually.

The conductor traveled about 50 miles from his home to the work site Monday through Friday, arriving in time to go on duty at 7:00 a.m. He said that on the Monday before the accident, he went off duty about 7:40 p.m. and retired about 9:50 p.m. On Tuesday, he awoke at 5:15 a.m., went on duty at 7:00 a.m., went off duty about 8:00 p.m., and retired about 9:45 p.m. He said he arose on Wednesday, January 5, the day before the accident, at about 5:00 a.m. and reported for work at 7:00 a.m. He went off duty about 8:11 p.m. and had been off duty for about 6 1/2 hours when the accident occurred.

**Brakeman**. Records revealed that the brakeman was originally hired on October 18, 1978. On November 26, 1978, he was promoted to yard foreman, helper, and trainman. On January 2, 1992, he was promoted to conductor.

The brakeman said he had not been distracted or preoccupied during his shift. Likewise, he said he was not aware that his engineer or conductor had been distracted or preoccupied while working.

The brakeman reported that he was "in good health" and that his most recent physical examination was conducted by his personal physician in December 2004. The

[27] The engineer would have had to have been called by 9:00 p.m. on January 4 to be able to start work at 7:00 a.m. on January 5 in Aiken. The NS representatives said that the job vacancy did not occur in time to allow a call by 9:00 p.m.

[28] Benadryl, an over-the-counter antihistamine containing diphenhydramine, relieves red, irritated, itchy, watery eyes; sneezing; and runny nose caused by hay fever, allergies, and the common cold. The medication can have sedating effects.

brakeman said he took multivitamins and a vitamin B complex. He also said he took a green tea supplement called MSM[29] as well as a supplement known as Laye.[30] He said both supplements were used to help alleviate pain in his joints. He said he was not sure whether he had taken either product the day before the accident. He said he had not used over-the-counter or prescription medications or alcohol or illicit drugs on the day before the accident.

The brakeman was an extra-board employee who was called to work as needed. He had not worked the Saturday or Sunday before the accident. He said that on Monday, he awoke at 4:25 a.m., reported for duty in Newberry, South Carolina, at 7:00 a.m., and went off duty at 1:30 p.m. He said he retired at 9:45 p.m. that evening. The brakeman worked train P22 on Tuesday. He said he awoke about 4:25 a.m. and reported for work at Aiken at 7:00 a.m. He went off duty at 7:31 p.m. and retired about 10:30 p.m. On Wednesday, the day before the accident, he said he awoke at 4:25 a.m., went on duty in Aiken at 7:00 a.m., and went off duty at 8:11 p.m. At the time of the accident, he had been off duty for about 6 1/2 hours.

### *Train 192*

**Engineer.** Records revealed that the engineer was originally hired on April 7, 1997. On August 25, 1997, he was simultaneously promoted to yard foreman, helper, trainman, and conductor. On December 12, 2001, he was promoted to engineer. His most recent engineer re-certification was issued on March 20, 2002. The engineer's most recent evaluation was on August 16, 2004. In the comments section, the examining officer noted, "Did well, no exceptions."

On Monday, January 3, 2005, he had been called for duty at 1:24 a.m. for an on-duty 3:00 a.m. start time. He went off duty later that morning at 8:30 a.m. He was called later that day, at 4:02 p.m., for an on-duty start time of 5:30 p.m. He went off duty the following morning, Tuesday, January 4, at 1:25 a.m. At 10:49 p.m., he was called for an on-duty start time of 11:59 p.m. He went off duty the following day, Wednesday, January 5, at 11:45 a.m. He was called at 11:07 p.m. that evening for an on-duty start time of 12:30 a.m., Thursday, January 6, for train 192. At the time of the accident, he had been on duty for about 2 hours 10 minutes.

**Conductor.** Records revealed that the conductor was originally hired on February 22, 1999. On August 30, 1999, he was simultaneously promoted to yard foreman, trainman, helper, and conductor.

On Sunday, January 2, the conductor had been called at 9:45 p.m. for an 11:10 p.m. on-duty start time. He went off duty the following day, Monday, January 3, at 4:34 a.m. He

[29] Methylsulfonylmethane (MSM) is also known as methyl sulfone or dimethylsulfone. It is advertised for relief of pain from arthritis, back pain, or muscle pain. No published research studies link MSM to any of the health claims made for it.

[30] Subsequent contact with the brakeman determined this product to be L-Lysine. L-Lysine is used by the body in building new tissue. It also promotes the body's protective substances, such as enzymes and antibodies. L-Lysine is a natural constituent in foods, with no known toxic effects.

was called the following day, Tuesday, January 4, at 1:00 a.m. for an on-duty start time of 2:30 a.m. He went off duty later that day at 12:33 p.m. He was called later that evening at 10:49 p.m. for an on-duty start time of 11:59 p.m. He went off duty the following day, Wednesday, January 5, at 11:46 a.m. He was called at 11:07 p.m. that evening for an on-duty start time of 12:30 a.m. on Thursday, January 6, for train 192. At the time of the accident, he had been on duty for about 2 hours 10 minutes.

### *Toxicological Testing*

In accordance with Federal requirements,[31] specimens were obtained from the engineer and conductor of train 192 and submitted for toxicological testing. The results were negative for alcohol and the screened substances.[32] Based on the circumstances of the accident and the fact that the crew of train P22 had been off duty for several hours when the accident occurred, the NS determined, in consultation with representatives of the Federal Railroad Administration (FRA), that neither the P22 crew nor dispatching employees were required by Federal regulations to undergo required postaccident chemical testing.

## Meteorological Information

The nearest National Weather Service reporting station to Graniteville, South Carolina, was about 17 miles away, in Augusta, Georgia. Sunset was at 5:34 p.m. Augusta weather at 6:53 p.m. on January 5, 2005, (the approximate time the P22 crew was preparing to depart Graniteville and return to Aiken) was as follows: winds from the south at 5 mph; visibility unrestricted at 10 miles; skies mostly cloudy; temperature 60° Fahrenheit (F); dew point 57° F. No precipitation was reported.

Augusta weather at 2:32 a.m. on January 6, 2005, (minutes before the collision and derailment) was as follows: winds from the south-southwest at 7 mph; visibility 5 miles; skies clear; temperature 55° F; dew point 54° F. No precipitation was recorded between 7:00 p.m. on January 5 and 3:00 a.m. on January 6.

## Operations and Track Information

The NS, which owns and operates the track in the accident area, is a subsidiary of the Norfolk Southern Corporation, headquartered in Norfolk, Virginia. The NS operates approximately 21,300 route miles of track in 22 eastern and southeastern States, the District of Columbia, and Ontario, Canada.

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[31] Title 49 *Code of Federal Regulations* Part 219, Subpart C.

[32] These substances included cannabinoids, cocaine, opiates, amphetamines, methamphetamines, phencyclidine, barbiturates, benzodiazepines, and ethyl alcohol.

The NS is the product of various railroad combinations, reorganizations, and consolidations. The largest NS predecessors were Norfolk & Western Railway and Southern Railway. The NS subsequently acquired a portion of the assets of Conrail, and the holdings of these former carriers make up the majority of the NS today.

The area in which the accident occurred is within the NS Piedmont Division. The R main line is a 190.52-mile track segment that extends from a junction to a main line near Charlotte, North Carolina, south through Columbia, South Carolina, to Augusta, Georgia. Numerous small towns and industries are near this track segment.

The segment of the R line at Graniteville is a non-signaled single main track controlled by a train dispatcher using a track warrant control system from Greenville, South Carolina. According to the terminal superintendent in charge of the territory, at the time of the accident, five trains were being operated daily over the track at Graniteville. These included two through freight trains in each direction operating between Augusta, Georgia, and Columbia, South Carolina, in addition to local train P22. The NS timetable speed from Columbia to Augusta at the time of the accident was 49 mph, in accordance with FRA limits for the territory, except in areas with reduced speeds because of curves.

The closest curve to the accident site is a left hand, 1º curve beginning at MP R178.45 and ending at MP R178.65. At MP R178.3 is the turnout to the industry track. The turnout uses a No. 10 switch[33] that is of similar construction and material to the main track. When lined for the diverging track, the maximum authorized speed through the switch is 15 mph. The switch was equipped with a 14-inch-diameter red and white reflective banner atop a 7-foot long banner shaft secured to the switch stand.

## Postaccident Inspections

### *Switch and Track*

The chlorine release that occurred as a result of the accident prevented Safety Board investigators from immediately entering the accident site. Because the Federal Bureau of Investigation (FBI) had trained hazardous materials teams with the equipment necessary to enter the site safely, the Safety Board requested the assistance of the FBI to document switch alignment, equipment, and other information. After being advised as to what to look for by Safety Board investigators, FBI representatives inspected the switch at the industry track turnout on January 7, 2005, the day after the accident. The switch was found to be lined and locked for the industry track. It showed no evidence of having been moved or tampered with. The switch points were in the proper position for the turnout, and the switch banner was in the red position, indicating that the switch was lined for the diverging track. No defects were noted with the switch points, switch throw rods, switch

[33] The number designation of a turnout switch refers to the angle at which the turnout track diverges from the main track, with higher numbers representing a more gradual angle. The investigation determined that the turnout into the Avondale Mills industry track led a train from the main line into an approximate 8º curve.

lugs, heel blocks, switch stand (base), or the switch lock. FBI investigators removed the switch handle and lock and the mast and banner and assisted the Safety Board in its investigation of these items.

On January 14, 2005, Safety Board investigators were able to inspect the accident site. A track inspection was performed on the industry track turnout and the track north and south of the turnout for approximately 1/10 mile. No main line track damage was incurred due to the accident, although a portion of the track north of the turnout had been removed to allow for cleanup.

The industry track turnout and the track south of it were intact and had no defects under Federal track standards. A section of the industry track near the switch had been damaged in the accident and had also been removed to allow for cleanup. The remainder of the industry track was intact. The NS maintains the track in the turnout to a limit of 295 feet, beginning at the switch points and extending into the industry track. An FRA inspection on January 14, 2005, identified no defects in this section of track.

Investigators reviewed track inspection records for the R line between Columbia, South Carolina, and Augusta, Georgia, for the time period between November 9, 2004, and January 5, 2005. NS inspection records for the track segment where the accident occurred, between MP R178 and MP R179, showed no defects for the 2-month period. The FRA requires that this class of track (class 4) be inspected twice weekly, and the records showed that the NS was in compliance with this requirement. The FRA also requires a monthly switch inspection. NS records showed the switch to have been last inspected on December 7, 2004. Records of a postaccident (January 8, 2005) FRA inspection of this track segment showed no defects.

### *Railcars*

After the derailment, the 26 cars from train 192 that had not derailed were decontaminated and moved to the Augusta Yard. On January 8, 2005, two locomotive units were coupled to that train, and an air brake test was performed. Both automatic and emergency brake applications were performed successfully.

After the brake tests, the cars were inspected by Safety Board investigators along with representatives of the NS, the State of South Carolina, and the FRA. A number of FRA safety appliance defects were found. In addition, inspectors found two broken brake shoes, one knuckle pin (coupler) defect, one leaking roller bearing seal, two piston travel defects, and one brake shoe that failed to center. The brakes also cut out on one car.[34] The identified defects would not have affected the performance of the train.

Train 192 was equipped with an automatic two-way end-of-train device (EOTD). Movement by the engineer of the automatic brake handle to the emergency position would automatically (via telemetry) cause the EOTD to activate emergency braking from the rear

[34] Freight car brakes are "cut out" when the branch pipe from the train air brake line to the car's air brake system is closed off, nullifying the brakes on that car without affecting the brakes of adjacent cars.

of the train, as well as from the head end. This system is designed to provide a more rapid brake application throughout the train and to ensure a complete brake application even in the event of a blockage in the air brake line. The postaccident inspection of the control stand in the cab of the lead locomotive of train 192 showed the automatic brake handle in the emergency position. The EOTD from train 192 was tested and found to function as designed.

## Tank Car and Hazardous Materials Information

### *Tank Cars*

A review of Association of American Railroads (AAR) certificates of construction for the derailed tank cars, as well as the postaccident inspection, revealed that each tank car was equipped with double-shelf couplers. These couplers are designed to resist vertical movement between joined couplers and thereby remain engaged during switching operations or accidents.

The sixth car in the train (SBLX 14146), containing chlorine, was built in 1997 by Trinity Industries, Inc., as a U.S. Department of Transportation (DOT) specification 105J500W tank car. The last periodic qualification of the car was in February 2004. The tank heads (the curved ends of the tank) were manufactured from 13/16-inch plate, and the shell was manufactured from 0.7874-inch carbon steel plate. Head and shell plates were specified as AAR specification TC-128-B normalized steel.[35] This car had a thermal protection system consisting of 2 inches of ceramic fiber covered with 2 inches of fiberglass. The AAR certificate of construction indicated that the 13/16-inch tank head, in combination with the insulation and the 0.1196-inch steel jacket, met the DOT tank-head puncture-resistance performance standards of 49 *Code of Federal Regulations* 179.16.

The seventh car in the train (GATX 17105), also containing chlorine, was built in 1979 by General American Transportation Corporation. It was a DOT specification 105J500W tank car that was originally built as a specification 105A500W tank car. The last periodic hydrostatic test was in January 2000. The tank heads were manufactured from 13/16-inch plate, and the shell was manufactured from 0.7874-inch carbon steel plate. Head and shell plates were non-normalized AAR specification TC-128-B steel. This car had a thermal protection system consisting of 4 inches of foam insulation. The tank car also met the DOT tank-head puncture-resistance performance standards of 49 *Code of Federal Regulations* 179.16.

The eighth car in the train (GATX 58326), containing sodium hydroxide solution, was built in June 1980 by ACF Industries, Inc., as a DOT specification 111A100W1 tank car. The last periodic hydrostatic test was in January 1998. The tank heads and shell were manufactured from 7/16-inch carbon steel plate. Head and shell plates were non-

[35] *Normalized steel* has undergone a heat treatment process that lowers the temperature at which the material transitions from ductile to brittle. The process also increases the amount of energy required to cause fracture. Since 1989, pressure tank car shells have been required to be fabricated from normalized steel.

normalized ASTM[36] specification A-515 grade 70, except for the center section of the shell, which was non-normalized AAR specification TC-128-B steel. This car had a total of 6 inches of fiberglass insulation.

The ninth car in the train (UTLX 900270), the punctured chlorine car, was built in 1993 by Union Tank Car Company. It was a DOT specification 105J500W tank car that was originally built as a specification 105S500W tank car. The last periodic qualification was in July 2004. The tank heads were manufactured from 53/64-inch plate, and the shell was manufactured from 0.777-inch carbon steel plate. Head and shell plates were specified as AAR specification TC-128-B normalized steel. This car had a thermal protection system consisting of 2 inches of ceramic fiber covered with 2 inches of fiberglass. This car was equipped with 1/2-inch full head shields.[37]

Chlorine tank cars such as the punctured car are pressure tested to 500 pounds per square inch, gauge (psig), compared to 300 psig for tank cars used to transport anhydrous ammonia and liquefied petroleum gas. Because of the higher test pressure, chlorine tank car walls are thicker than those of lower-rated pressure tank cars.

### *Hazardous Materials*

Four of the five tank cars that derailed (three car loads of chlorine and one car load of sodium hydroxide) were shipped by Olin Chlor Alkali Products (Olin) of Augusta, Georgia. The three tank cars containing chlorine were loaded between December 31, 2004, and January 4, 2005. Loading of the tank car that was punctured in the derailment had been completed at 3:10 a.m. on January 4. The recorded loading pressure for each car was 22 psig, which equates to a chlorine temperature of about 12º F. The estimated temperature of the chlorine (and the tank car steel) at the time of the derailment was 26º F.

The cars each contained 180,000 pounds (about 13,830 gallons)[38] of chlorine. According to Olin's material safety data sheet, chlorine is a poisonous gas, an oxidizer, and a marine pollutant. It has an IDLH value[39] of 10 parts per million (ppm). If inhaled, chlorine will react with moisture in the respiratory tract and lungs to form hydrochloric acid, resulting in inflammation of these tissues. Severe exposure can result in pulmonary edema, suffocation, and death. Chlorine has a vapor pressure of 31 psig at 26º F and a vapor density of 2.5 (heavier than air). At atmospheric pressure, chlorine changes from a

[36] ASTM International is a voluntary standards organization originally known as the American Society for Testing and Materials.

[37] A *head shield* is a supplemental heavy steel plate required by Federal regulation on the ends of some hazardous materials tank cars to reduce the likelihood that a tank head will be punctured by the coupler of an adjacent car in the event of excessive end impact or derailment.

[38] Calculations made using a specific gravity for chlorine of 1.56.

[39] The *IDLH* (immediately dangerous to life and health) *value* is an atmospheric concentration of any toxic, corrosive, or asphyxiate substance that poses an immediate threat to life, or would cause irreversible or delayed adverse health effects, or would interfere with an individual's ability to escape from a dangerous atmosphere. The Environmental Protection Agency uses 10 percent of the IDLH value when determining that a release has reached a level of concern for public exposure.

liquid to a gas at –29º F. It is miscible[40] in water. It is considered corrosive because it forms hypochlorous acid and/or hydrochloric acid when combined with water.

The sodium hydroxide car contained 191,750 pounds (15,340 gallons)[41] of a 50-percent solution of sodium hydroxide in water. The solution is corrosive, and prolonged contact can cause permanent skin damage.

The fifth derailed tank car was shipped by Westvaco Corporation from De Ridder, Louisiana. The car was listed as empty but contained a residue of rosin, which is transported as an elevated temperature liquid. Rosin is normally a solid, and in this form is not regulated by the DOT as a hazardous material. The material is heated to 212° F or more for loading and unloading and at such temperatures is considered a burn hazard.

## Tests and Research

### *Sight Distance Tests*

On March 29, 2005, Safety Board investigators conducted sight distance tests at the accident scene using locomotive equipment similar to that in use on train 192 at the time of the accident. The tests were conducted at the same time of day as the accident and under similar weather and lighting conditions. During the tests, the test engineer was seated on the left (west) side of the locomotive, as had been the accident engineer. A test conductor was seated on the right (east) side of the locomotive.

The test determined that the red reflection from the switch banner could be first observed from the engineer's seat at a distance of 1,461 feet from the switch as the train transitioned from curved to tangent (straight) track. The red reflection was first visible on the conductor's side of the locomotive at 1,339 feet from the switch. The test also determined, however, that the red reflection could not be identified by either crewmember as a switch banner until the train was within 566 feet of the switch when the train headlight illuminated the banner. The test revealed that the position of the switch points (which indicate which way the switch is lined) could not be seen by the crew until the train was 220 feet from the switch stand.

The tests showed that a number of warning and signal lights were visible to the crew of a train approaching the industry track switch. Canal Street and Trolley Line Road intersected with Aiken Road about 393 feet north of the switch on either side of the NS main line. The grade crossing at these intersections was protected with flashing lights and bells. A total of eight pairs of red flashing lights at the intersections activated when a train was 1,927 feet south of the crossing, or 1,534 feet from the switch. Additionally, about 281 feet north of the switch and just east of the main track was a wayside light indicating the switch position at the Vaucluse Siding.[42]

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[40] *Miscibility* refers to the ability of a liquid or gas to dissolve uniformly in another liquid or gas.

[41] Calculations made using a specific gravity for a 50-percent solution of sodium hydroxide of 1.5.

[42] See the "Other Information" section of this report for more information on switch position indicator lights.

The driver of the taxi that transported the P22 crew on January 5 said that as he left the area with the crew, he drove along Canal Street, on the west side of the main line. The distance from the centerline of that roadway to the industry track switch stand measured 21 feet. Investigators determined that the position of the switch would have been clearly visible to an occupant of a vehicle proceeding along the road.

### *Event Recorder Data*

Each of the three locomotive units involved in the accident was equipped with an event data recorder. The lead locomotive of train 192 used magnetic tape as a recording medium; the trailing unit and the single locomotive of train P22 were equipped with solid-state devices. Magnetic tape data were read on scene; the solid-state units were shipped to Safety Board headquarters in Washington, D.C., where the information was downloaded and analyzed by the Safety Board's Vehicle Recorders Division.

The clock from each event recorder was correlated to the approximate reported time of the collision. Using the Safety Board's data analysis software, the data were verified for accuracy by comparing the data recorded before the collision against the operating range and limitations of the locomotives and against the known preaccident operation of the train. The data recorded for traction motor current from the trailing locomotive of train 192 was found to be inconsistent with the operation of the train. No evidence was found of damage or recorder malfunction. Because damage from the accident prevented the testing of the locomotive, the reason for the anomalous data readings could not be determined. The remaining data from the trailing locomotive were found to be consistent with the operating range and limitation of the equipment.

**Train P22**. The crew of local train P22 stated that the train arrived at the industry track about 6:10 p.m. on January 5. Event recorder data indicate that the train came to a stop at approximate recorder time 6:08:51 p.m. The train remained at a stop until recorder time 6:09:57, after which the train made a series of forward and reverse movements with the throttle handle and automatic brake handle being manipulated. The speed during these movements remained below 11 mph. At recorder time 6:52:57 p.m., the speed indicated 0 mph; the throttle was in idle; and the automatic brake was in the 26-pound application position. No further operational control changes were recorded.

**Train 192**. Event recorder data from the magnetic tape recorder on the lead locomotive indicated that at approximate recorder time 2:10:41 a.m., consistent with the reported time of departure from Augusta, the train brake was released and the speed began to increase. Train speed continued increasing with the throttle handle in the idle position until 2:12:36, when the throttle handle was moved to notch 3 and the speed indicated 9 mph. The train continued north with the throttle manipulated between the idle and notch 3 positions while the speed fluctuated between 9 and 12 mph.

At recorder time 2:22:30 a.m., the throttle handle was placed in notch 4, and the speed began increasing. The speed continued increasing while the throttle handle was manipulated between notch 3 and notch 8, and at 02:29:47, the data indicated a speed of 49 mph, which was the maximum speed attained during the trip from Augusta to Graniteville.

The train continued northbound with the speed fluctuating between 44 and 47 mph. At recorder time 2:36:30 a.m., the throttle handle was increased to notch 8 while the train traveled at 44 mph. Data indicated that the throttle handle remained in notch 8 until 2:38:11 with the train speed indicating 47 mph. The throttle was decreased to notch 6 with the speed continuing to increase to 48 mph. At recorder time 2:38:37, the throttle handle was placed in notch 4 with the speed remaining at 48 mph. At 2:39:00, approximately 467 feet from the final resting point of the train,[43] the speed indicated 47 mph. At 2:39:03, approximately 268 feet from the final resting point, traction motor current rose sharply, indicating an increase in load on the motors. The indicated speed at that point was 42 mph, and the train was decelerating rapidly. At 2:39:06, approximately 117 feet from the final resting point, the automatic brake (train brakes) indicated an emergency; the independent (locomotive) brake toggled on; the throttle was in the idle position; and the speed was 26 mph. A second, larger spike in traction motor current occurred at 2:39:15. At 2:39:20 a.m., speed indicated 0 mph.

### *Laboratory Examination and Testing*

The Safety Board's Materials Laboratory examined a portion of the tank from the ruptured ninth car on the train. This examination revealed that a 2 1/2-inch-long fracture area in the center of the tank shell impact area, including the origin of the crack, separated in a ductile mode. The remaining portions of the crack on either side of the ductile fracture area separated in a brittle mode.

The Safety Board performed Charpy impact testing of the steel from the tank car shell. The Charpy testing showed that the ductile-to-brittle transition temperature of the steel plate from the shell of the ruptured tank was 40º F for specimens oriented transverse to the rolling direction of the steel plate and 0º F for specimens oriented parallel to the rolling direction of the steel plate. The estimated temperature of the chlorine (and the tank car steel) at the time of the derailment was 26º F. The chemical composition and tensile properties of the head and shell material met the specifications for AAR TC-128-B normalized steel.

## Other Information

### *Accidents Involving Improperly Lined Switches*

According to FRA safety data, "Human factors constitute the largest category of train accident causes, accounting for 38 percent of all train accidents over the last 5 years." The data show that the leading cause [of human factor accidents] for 2004 was improperly lined switches, which alone accounted for 16 percent of human factor accidents in the last 4 years."[44]

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[43] Distance estimates are based on time and speed calculations; they do not account for any wheel sliding or skidding that may have occurred during the accident sequence.

[44] Douglas Taylor (Staff Director Operating Practices, FRA Office of Safety), "FRA's Operating Rules Working Group Spurs Action to Address Critical Safety Issues," *American Short Line Railroad Association Safety Bulletin No. 9*, August 2005, p. 2.

In 1999, the P22 conductor in the Graniteville accident was dismissed from service for his failure to "properly restore the main track switch…resulting in your endangering the safety and lives of other employees.…" Documentation pertaining to this incident, which occurred on March 10, 1999, disclosed that a train, traveling about 30 mph, encountered the misaligned switch at 3:05 a.m. the following morning. The engineer saw the red switch target and placed the train in emergency braking, coming to a stop about 5 car lengths from the switch. The NS suspended the conductor from service on the day of the incident and dismissed him from service after an investigation on March 31, 1999. The conductor was reinstated on April 11, 1999.

On January 8, 2005, two days after the Graniteville accident, a Burlington Northern Santa Fe Railway Company (BNSF) freight train was unexpectedly diverted onto an industrial track in Bieber, California. The BNSF train struck two loaded grain cars, derailing 7 locomotives and 14 cars. Two railroad employees were injured.

On September 15, 2005, during the preparation of this accident report, a southbound Union Pacific (UP) freight train was unexpectedly diverted into a passing siding at Shepherd, Texas, where it struck a northbound local train that had been parked on the siding track to allow the southbound train to pass. The conductor of the parked train had earlier lined the northernmost siding switch to allow the local to back from the main line into the siding where it was to await the southbound train. To avoid violating Federal hours-of-service regulations, the local train crew secured the train in the siding and, without relining the switch at the north end of the siding, departed in a contracted taxi. When the taxi was about 20 miles from Shepherd, the conductor realized he had left his keys in the switch lock at the siding and insisted that the driver return to Shepherd. Meanwhile, a 3-person relief crew had boarded the local train. As the southbound train approached, the local train's engineer remained aboard the locomotive while the other two crewmembers dismounted to inspect the passing train from the ground. Instead of proceeding down the main line, the southbound train entered the siding via the improperly lined switch and struck the standing train. The engineer of the local train was killed, and four other crewmembers of the two trains were injured.

### *Postaccident FRA Safety Advisory*

In response to the Graniteville accident, the FRA, on January 13, 2005, issued Safety Advisory 2005-01, "Position of Switches in Non-Signaled Territory," to

> advise all railroads to review their operating rules and take certain other action necessary to ensure that train crews who operate manual (hand-operated) main track switches in non-signaled territory restore the switches to their normal position after use.

The advisory informed railroads of the circumstances of the Graniteville accident as well as of the January 8, 2005, BNSF accident.

The safety advisory referenced rules promulgated by the UP and the BNSF railroads regarding the relining of switches. On October 1, 2004, the UP adopted a requirement that before reporting clear of the limits of a track warrant, the crewmember releasing the track warrant must first inform the train dispatcher that main track switches have been restored to their normal positions. If the crew does not provide this information, the train dispatching system prompts the train dispatcher to ask for it. The change was made because of a September 29, 2004, collision that occurred at Thomaston, Texas, in which a Texas Mexican Railway Company (TM) crew released a track warrant without verifying that a siding switch was properly lined for the main track. A southbound UP train entered the siding and collided with an unattended TM train.

On October 31, 2004, the BNSF adopted a requirement that before releasing a track warrant, a train crew must report to the train dispatcher the position of any switch the train has used. The dispatching system will not allow a track warrant to be cleared until the dispatcher confirms the switch position through a job briefing with the crew. According to the FRA advisory, this change was made as the result of a recommendation from a BNSF division safety team. The safety team was concerned about incidents in which crews in a particular subdivision had forgotten to reline main line switches. The BNSF rules department issued this change across the BNSF system.

In the safety advisory, the FRA "strongly urged" railroads to (1) ensure that their operating rules contain a provision similar to those of the UP and the BNSF that require train crews who manually operate main line switches in non-signaled territory to report to the dispatcher that the switches have been restored to the normal position before the crews report clear of the main track, (2) require that the conductor of a crew working in non-signaled territory, before reporting clear of main track, sign a switch position awareness form that lists the name and location of any switch operated by any member of the crew and the time each switch was relined for the main line, (3) require that the switch position awareness form be submitted to a designated railroad official at the completion of each tour of duty, (4) require that railroad officials review the forms for accuracy and to use the results in the railroads' testing and proficiency programs, and (5) ensure that the revised rules, procedures, and forms are immediately disseminated to all affected operating personnel.

The advisory stated that the FRA is considering the need for additional measures, such as regulatory action or further advisories.

### *FRA Human Factors Working Group*

On May 18, 2005, the FRA's Railroad Safety Advisory Committee[45] established an operating rules working group to review the primary human factor causes of train accidents and incidents and to recommend methods of reducing those accidents/incidents and the resulting employee injuries. The working group was tasked with reporting its findings and recommendations to the full committee by February 10, 2006.

### *FRA Emergency Order*

In follow-up to Safety Advisory 2005-01, the FRA, on October 20, 2005, issued Emergency Order No. 24, "Emergency Order Requiring Special Handling, Instruction and

[45] The Railroad Safety Advisory Committee is made up of representatives of government, industry, and other entities having an interest in railroad safety. The FRA established the committee in 1996 to advise the FRA and develop consensus recommendations on safety issues.

Testing of Railroad Operating Rules Pertaining to Hand-Operated Main Track Switches." The order states that:

> …public safety compels issuance of this Emergency Order (EO) requiring railroads to modify their operating rules and take certain other actions necessary to ensure that railroad employees who dispatch non-signaled territory or who operate hand-operated main track switches…in non-signaled territory ensure the switches are restored to their proper (normal) position after use.

In the "Background" section of the order, the FRA notes that the year 2004 saw a marked increase in the "frequency and severity of collisions resulting from improperly lined main track switches…." The order states that after the issuance of the January safety advisory, and with the exception of two accidents that occurred shortly after the advisory was promulgated, "there was a respite of nearly six months in accidents resulting from improperly lined switches in non-signaled territory." However, in July 2005, two such accidents occurred, and within a 28-day period in August and September, according to the emergency order, three additional, more serious accidents occurred:

On August 19, 2005, a Kansas and Oklahoma Railroad freight train, operating at 26 mph in Nickerson, Kansas, encountered an improperly lined switch, entered a siding, and struck a standing cut of cars. The train's engineer was severely injured.

On August 21, 2005, a UP freight train, operating at 30 mph, was unexpectedly diverted into a siding in Heber, California, where it struck a standing cut of cars. The control compartment of the lead locomotive was destroyed. The three crewmembers "survived only by quickly throwing themselves on the floor of the locomotive immediately before impact."

The third serious accident was the previously described September 15, 2005, accident on the UP railroad in Shepherd, Texas.

The July-through-September accidents, according to the FRA in its emergency order, were a "clear indication that the Safety Advisory ha[d] lost its effectiveness." The emergency order was thus issued:

> …to accomplish what the Safety Advisory could not: implement safety practices that will abate the emergency until [the] FRA can complete rulemaking….

The FRA states that, using the advice contained in the February 2006 report of the previously referenced Railroad Safety Advisory Committee human factors working group, its "goal is to publish a proposed rule in 2006, and a final rule soon thereafter."

The emergency order identifies certain actions that must be taken by railroad employees who operate hand-operated main line switches in non-signaled territory or who dispatch in non-signaled territory. Those actions may be summarized as follows:

- All employees subject to the emergency order must receive both initial and periodic instruction on the emergency order and on the railroads' operating rules related to hand-operated switches in non-signaled territory. Railroads must maintain records of the training.

- Employees who operate the switches are responsible for restoring them to their normal positions.
- Employees releasing track authority must report to the dispatcher that all main line switches have been restored to their appropriate positions. Additionally, the dispatcher must confirm that the conductor and engineer have initialed the switch position awareness form (which the FRA recommended in its safety advisory that railroads adopt).
- Employees operating hand-operated switches must complete a switch position awareness form, and all the information required by the form must be entered before an employee reports clear of the limits of track authority.
- Job briefings must be held by employees in connection with the operation of hand-operated main track switches in non-signaled territory. A briefing must be conducted before the work is done, each time the work plan is changed, and when the work is complete.
- Each time a train crewmember changes the position of a hand-operated main line switch in non-signaled territory, the crewmember, while at the switch, shall inform the engineer by radio of the switch name, location, and position. The engineer must acknowledge the information before any movement can occur.
- Operational tests and inspections must incorporate the requirements of the emergency order.
- Every affected employee will be provided a copy of the emergency order, and receipt must be acknowledged in writing.

The emergency order provides relief for railroads that provide a level of safety the FRA considers equivalent to the emergency order. As outlined in the order, relief is automatically granted when (in reference to hand-operated switches in non-signaled territory):

- A railroad's operating rules require that trains approaching the switches be prepared to stop;
- The switches are protected by distant switch indicators; or
- The switches are automatic or self-restoring and are protected by switch point indicators [described in the next section of this report], unless those switches are operated by hand.

The emergency order provides for a civil penalty of up to $27,000 for any person (including individuals or corporate entities) violating the requirements of the order. Steps to implement the order must begin immediately, with full implementation required by November 22, 2005.

### *Switch Position Indicators*

Some railroad switches, even in non-signaled territory, are equipped with switch circuit controllers that can detect the switch position and alert the crew of an approaching train if the switch is improperly lined. In signaled territory, the position of the switch is conveyed to the train crew through a corresponding wayside signal. In non-signaled territory, depending on the type of switch system in use, the crew can be alerted by wayside indicator lights or by a radio message broadcast on the train crew's radio channel.

The switches for the siding at Vaucluse,[46] about 1.1 miles north of the industry track, are equipped with switch position indicator lights. One wayside light at the switch signifies the switch position, and if the switch is not lined for the main line, another wayside light farther along the track alerts an oncoming train in time for it to slow and stop short of the switch. Unlike the hand-operated switch at the industry track, the switches at Vaucluse are "spring" switches.[47] If a train is to use one of these switches to enter the siding from the main line, a crewmember must still line the switch by hand and reline it for the main line after the train is in the siding. But while the switch is lined for the main line, a train may move from the siding onto the main line without the need to reposition the switch. As the train moves through the switch, the train wheels force open the switch points for the movement. Once the last wheels of the train have cleared the switch, a powerful spring, hydraulically assisted, automatically returns the switch points to their normal position (lined for the main line).

Because a crew can move their train through a spring switch onto the main line without manually manipulating the switch, no crewmember tends the switch after the train has passed through. If the spring switch is equipped with a switch circuit controller, the controller will detect the switch position and if, for example, an obstruction has prevented the switch from returning to the normal position or if the switch has been left lined for the siding, the lights at and in advance of the switch will display the appropriate aspect to the next train approaching that location.

### *Postaccident Action by NS*

Immediately after the accident, the NS amended its Operating Rule 181 to address manually operated main track switches in non-signaled territory. Under the new rule (Operating Rule 181a), train and engine crews, when reporting clear of track authority limits in non-signaled territory, must advise the dispatcher or control operator of:

- The total number of hand-throw main track switches operated within the track authority;
- The name and location of each main track switch operated;
- The restoration and securement of main track switches in their normal (main line) position.

The rule states that train dispatchers or control operators within non-signaled territory are not to clear a track authority until notified by the train or engine crew that each hand-throw main track switch that has been operated has been locked in normal position.

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[46] This is a passing siding paralleling the main line with a switch at the north and south ends.

[47] The NS has not equipped switches other than spring switches with switch position indicator lights or other methods of alerting train crews of improperly lined switches.

### *Hours of Service Act*

Congress enacted the original Hours of Service Act in 1907. The intent of the act was to promote railroad safety by limiting the number of hours train crewmembers may remain on duty and by requiring railroads to provide them with a minimum rest period between shifts. The act, which has been revised and amended since its enactment, is codified in FRA regulations at 49 *Code of Federal Regulations* Part 228 and applies to any railroad employee engaged in or connected with the movement of a train. The act provides that train employees may not remain on duty for more than 12 consecutive hours or 16 hours in an emergency.[48] The Hours of Service Act further provides that a covered employee must be given at least 8 consecutive hours off after a tour of duty of less than 12 duty hours, and 10 consecutive hours off after a tour of duty of 12 hours or more.

When a train crew cannot reach a scheduled or convenient crew change point within 12 duty hours, the train must stop so that a replacement crew can take over. The crewmembers being relieved are paid for any time they spend "deadheading" back to the terminal; however, this time is referred to as "limbo time," as it is not considered to be time on duty or time off duty.[49]

The hours-of-service limits for the conductor and brakeman of train P22 expired at 7:00 p.m. After the crew arrived at the Aiken Yard, the conductor and brakeman finished the required paperwork, and the entire crew was shown off duty at 8:11 p.m. Records showed that on 10 of the 30 working days before the accident, train P22 crews had spent time on paperwork after having been on duty for 12 hours in train or engine service. An FRA representative responsible for enforcing the Hours of Service Act told the Safety Board that any work, including paperwork, done on behalf of the railroad beyond the allotted 12 hours is considered a violation of the act.

In Safety Board interviews, the P22 crew working the day before the accident said that they were not aware that doing paperwork after 12 hours of operating a train could be considered a violation of the Hours of Service Act. They indicated that they understood the law covered only the movement of railroad equipment, not subsequent time spent in administrative duties. NS managers told the Safety Board that they were unaware that train crews were working outside the time limits. The computer time submissions by train crews were used primarily for accounting and pay purposes and were not used by operations managers to audit train crew activities. The FRA requires railroads to file excess-service reports when covered employees exceed the 12-hour limit. The NS had submitted no such reports for service performed by the P22 crew before the accident. After the accident, the FRA cited the NS for violations of the Hours of Service Act.

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[48] The Hours of Service Act does not specifically refer to "emergency" or "emergencies," but to "casualties, unavoidable accidents, Acts of God," and is interpreted by the FRA as "a cause not known to the carrier or its officer or agent in charge of the employee at the time the said employee left the terminal, and which could not possibly be foreseen."

[49] The amount of time that a train crew spends deadheading to (as opposed to from) an assignment is considered on-duty time and is included when calculating total duty time.

# Analysis

## The Accident

NS train 192 was operating under track warrant authority on January 6, 2005, when it departed Augusta, Georgia, bound for Columbia, South Carolina. The crew had every reason to believe that no other trains would be occupying their track and that all switches would be set for the main line. The 30-minute trip was uneventful from Augusta to Graniteville.[50]

Train 192 continued operating at near the maximum authorized speed of 49 mph as it approached the industry track switch, which was improperly lined for the industry track instead of the main line. Event recorder data indicated that the train was traveling about 47 mph just before it encountered the switch and was diverted into the industry track. At a point north of the turnout switch, as the train entered the 8º left-hand curve of the industry track, the first car aft of the locomotives rolled toward the right and derailed. As the car toppled to the right, it became uncoupled from the locomotives, and the train's emergency brakes applied. The movement of the first car off the rails also caused the aft end of the second locomotive to derail.

Almost simultaneously with the separation of the first railcar, the front of the lead locomotive of train 192 struck the front end of the locomotive of standing train P22, which had been left on the industry track the previous evening. The derailment and impact likely accounted for the spike in traction motor current recorded at 2:39:03 by the event recorder in the lead locomotive of train 192. The speed of the locomotives, which were rapidly decelerating, was about 42 mph at that point.

With the collision and derailment, the cars coupled behind the first railcar were carried onward toward the derailed first railcar as a result of "run-in" momentum. The 2nd through 14th cars in the consist then progressively derailed as they made contact with the preceding derailed cars, with the individual cars coming to rest in a wreckage pileup. The 15th and 16th cars in the consist derailed but did not become entangled in the pileup.

The collision of the two locomotives derailed the standing train P22 locomotive and propelled it about 217 feet northward (along the track). The P22 locomotive came to rest about 5 feet south of the Hickman Street pavement edge, remaining upright and somewhat aligned with the track.

The lead locomotive of train 192 traveled about 145 feet after the collision and came to rest an estimated 77 feet south of the Hickman Street pavement edge, which is about 487 feet to the north of the switch for the industry track turnout.

[50] The accident scenario outlined in this section is based on postaccident inspections, physical evidence, and event recorder data.

The investigation revealed that the improperly lined switch had most recently been used by the crew of local train P22 about 8 hours before the accident. The crew had lined the switch for the industry track in order to place two cars at the Avondale Mills plant. No crewmember remembered relining the switch for the main line before they boarded a taxi and returned to the terminal.

## Exclusions

Inspection records and postaccident examination revealed that the track and switch in the derailment area were in good condition on the day of the accident. The non-derailed cars from train 192 were tested, and no defects were found that would have affected the operation of the train or altered its performance. The train 192 crewmembers were qualified for their duties; they had received adequate time to rest before being called for work; and they had been on duty for only about 2 hours 10 minutes when the accident occurred. Postaccident toxicological testing was negative for the train 192 engineer and conductor. The Safety Board therefore concludes that neither train equipment defects nor track condition were causal or contributory to this accident. The Safety Board further concludes that, in regard to the crew of train 192, fatigue, crew training and qualifications, and drugs and alcohol were not factors in this accident.

The train P22 crew was experienced and qualified for the position each crewmember held on the day before the accident. Each crewmember had had sufficient off-duty time to have been well-rested before reporting for duty on January 5, 2005. Because about 6 1/2 hours elapsed from the time the P22 crew went off duty until the accident occurred, toxicological testing of the train P22 crew was not required or performed. Crewmembers said they had not used alcohol or illicit drugs before or during duty on January 5, and no evidence was found to suggest such use. The Safety Board therefore concludes that, in regard to the crew of train P22, neither crew qualifications and training nor fatigue were causal or contributory to this accident, and no evidence was found to suggest drug or alcohol use.

## Emergency Response

Local emergency response agencies were notified via 911 calls within about 1 minute of the accident. The fire chief and other resources of the Graniteville, Vaucluse, and Warrenville Volunteer Fire Department were en route to the scene about 1 minute thereafter. When the first-arriving responders reported breathing difficulties, the fire chief ordered his resources to stand by and not approach the scene, which proved to be a prudent action. When the fire chief arrived and was himself almost overcome by the toxic fumes, he directed a mass evacuation of the area. Within about 13 minutes of dispatch, the fire chief began marshaling his firefighting personnel and equipment at a staging area upwind of the toxic gas release site. The fire chief also began establishing incident command, requested mutual aid from nearby communities, requested weather information, and asked that the reverse 911 system be activated. Within about 27 minutes of dispatch, equipment and personnel were being successfully staged at what was later identified as a "forward command" site. Within about 34 minutes of dispatch, all Aiken County fire resources were placed on standby.

Within 53 minutes of the initial dispatch, the first of four decontamination stations was being organized. Within 69 minutes of dispatch, several firefighter entry teams, wearing personal protective equipment and riding in privately owned pickup trucks, were dispatched to the accident site. The teams transported individuals or groups of people who had been exposed to the gas vapor to one of the decontamination stations before returning to the scene to repeat the search and rescue cycle. The technique used by the entry teams, which allowed them to rapidly cycle into and out of the "hot zone," proved to be a particularly efficient and expeditious means of evacuating those individuals who were in the most danger because of their proximity to the accident site.

A review of the causes of death of the fatalities occurring in the field revealed that the mechanism of death for all the fatalities was asphyxia that occurred within minutes of exposure to the chlorine gas. This finding suggests that many, if not all, of the civilian fatalities in this accident occurred within the minutes that elapsed before emergency responders arrived on the scene or were able, because of the toxic fumes, to begin a safe search and rescue effort.

Based on the promptness of the dispatch of emergency response resources to the scene; the immediate implementation of the incident command system; the timely request that additional mutual aid emergency response resources be dispatched to the scene; and the relatively prompt search and rescue, evacuation, and decontamination efforts, the Safety Board concludes that the execution of the emergency response to this accident was timely, appropriate, and effective.

## Performance of Train P22 Crew

The crew of local train P22, working out of Aiken, South Carolina, completed their work along the NS main line in the Graniteville area about 7:00 p.m. on January 5, 2005. No other trains or crews occupied or worked along the main line between the time the P22 crew left the industry track and the arrival of train 192 about 7 1/2 hours later.

The P22 conductor stated that his crew arrived at the industry track about 6:10 p.m. the day before the accident. Because the brakeman and conductor had been on duty since 7:00 a.m., they had only 50 minutes to complete their work at the mill and safely secure their train before reaching the maximum 12-hour limit imposed by Federal hours-of-service regulations. The brakeman recalled being "pushed for the [hours of service] law" as he worked in the Avondale Mills area. The engineer said that throughout the workday, both the brakeman and conductor held job briefings at various places they worked, but no such job briefing was held once the crew arrived at the industry track. The engineer later speculated that the reason no job briefing was held might have been that the conductor and brakeman were "in a hurry."

The brakeman told investigators he was sure "in his mind" that everything was lined properly when he left the Avondale Mills area the evening before the accident. But he also said he was not "100 percent" sure that he had relined the main line switch before departing. Postaccident inspection revealed that the switch was lined and locked for the industry track, as it had been when train P22 used the switch on the evening of January 5. The switch showed no evidence of tampering, and no other trains used the track in the area from the time the train P22 crew left until the accident the next morning. The Safety Board therefore concludes that the crew of train P22 failed to reline a main line switch after using it, leading to the subsequent and unexpected diversion of train 192 into an industry track where it struck train P22 and derailed.

Perhaps the most vexing question when considering the circumstances of this accident is how an experienced train crew could fail to execute a simple action—relining a switch—that they had performed many times before and that, in fact, was a routine part of their jobs. As the crew wrapped up their work at the industry track and departed the area, none of them realized that a critical final task had been omitted.

One expert who studies the nature of errors is James Reason, professor emeritus of psychology at the University of Manchester in Manchester, UK. Reason has characterized errors of omission as a "particularly worthwhile target since the failure to carry out necessary steps in the performance of a task is probably the single most common human error type."[51]

In a paper,[52] Reason discusses the nature of omissions and how they occur. He identifies a number of task features that are likely to increase the probability that a particular step in a task will be omitted. The task features Reason identified are as follows:

- The greater the informational loading of a particular task step—that is, the higher the demands imposed upon short-term memory—the more likely it is that items within that step will be omitted.[53]
- Procedural steps that are functionally isolated, that is, ones that are not obviously cued by preceding actions nor follow in a direct linear succession from them, are more likely to be left out.
- Recursive or repeated procedural steps are particularly prone to omission. In cases where two similar steps are required to achieve a particular goal, the second step is the one most likely to be neglected.[54]

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[51] J. Reason, "How Necessary Steps in a Task Get Omitted: Revising Old Ideas to Combat a Persistent Problem," *Cognitive Technology*. 1998; 3:24-32.

[52] J. Reason, "Combating Omission Errors Through Task Analysis and Good Reminders," *Quality and Safety in Health Care*. 2002; 11:40-44.

[53] D. A. Norman, *The Psychology of Everyday Things.* New York: Basic Books, 1988.

[54] C. Baber and N. A. Stanton, "Task Analysis for Error Identification: A Methodology for Designing Error-Tolerant Consumer Products," *Ergonomics*. 1994; 11:1923–41.

- Necessary steps that follow the achievement of the main goal of a task are likely to be omitted. This is an instance of a general principle: Steps near the end of a task sequence are more prone to omission. Such "premature exits" are due in part to the actor's preoccupation with the next task, particularly when the current activity involves largely routine actions.[55]
- Steps in which the item to be acted upon is concealed or lacking in conspicuity are liable to omission.
- Steps following unexpected interruptions are especially prone to omission. This can occur because the person loses his or her place in the action sequence or because some unrelated action is unconsciously "counted in" as part of the task sequence.[56]
- In tasks that involve departures from standard operating procedures or from habitual action sequences, the intended actions may be supplanted by the more frequently used routine in that context and thus omitted.
- Actions that are triggered by weak, noisy, or ambiguous signals are likely to be omitted.

Reason discussed a study involving frequent users of office copiers that illustrated the potential for omission errors created by the above task features. Based on these features, researchers correctly predicted that the most common error reported by copier users who manually copied multi-page documents would be the failure to remove the last page of the original after copying was complete. This failure was predictable because:

- The emergence of the last copy page is a strong, but false, signal that the job is complete. That is, the main goal of the activity (copying) is achieved before completion of all the necessary steps.
- This false completion signal gains influence because of its proximity to the presumed end of the activity. As the last page is copied, attention to the subsequent task increases.
- As the last sheet is copied, it is no longer necessary to insert another original. This leaves removing the last original page a functionally isolated act. Up until this point, removal of an original page has been cued by the need to place the next one.
- The closed copier lid conceals the last sheet of the original, so there is no visible reminder to remove it.

The primary purpose of the exercise was to demonstrate that task features that are likely to provoke frequent omissions can be identified and, once they are identified, steps can be taken to reduce the frequency of such errors.

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[55] J. Reason, *Human Error*. New York: Cambridge University Press, 1990.

[56] J. Reason, *Human Error*.

Some of the task features that have been identified as leading to omission errors were evident in the Graniteville accident. Some of the more important of these features are as follows, illustrated by events from the accident sequence:

> Procedural steps that are functionally isolated, that is, ones that are not obviously cued by preceding actions nor follow in a direct linear succession from them, are more likely to be left out.

When the crew arrived at the Avondale Mills plant, they immediately undertook a series of steps that would permit them to achieve their objective of placing two cars at the industry track. This included the conductor's getting off the locomotive and leaving the train to unlock gates and prepare switches near the industry track, the brakeman and engineer's continuing on toward the switch, the brakeman's dismounting the train and lining the switch for the industry track, the engineer's backing the train into the industry track, and the brakeman and conductor's continuing with their switching and placement of cars.

In this sequence of actions, each step proceeded in a direct linear fashion, one step leading naturally to the next. Had the initial plan called for moving the train onto the industry track and leaving it there without returning to the main line, relining the switch after the train was on the industry track would have been a natural next step. Similarly, had the crew been able to finish their work at the industry track and take the train to Warrenville as they planned, relining the switch once the train returned to the main line would have followed naturally in an organized sequence.

As it was, the 12-hour duty limit interrupted the process of planned, deliberate, sequential steps. Now, instead of completing their job at the mill, continuing southbound, and securing their train, the crew had to secure the train in place. This required that the crew switch and place cars to get the train clear of the main line and road crossings and do it within a strict time limit. They were just able to complete this work before their maximum on-duty time expired.

The last-minute change in plans created a new sequence of events that left one critical step functionally isolated—that of relining the main line switch. Because the train did not return to the main line, relining the main line switch was no longer part of an organized process of sequential steps and was thus neglected.

> Necessary steps that follow the achievement of the main goal of a task are likely to be omitted. This is an instance of a general principle: Steps located near the end of a task sequence are more prone to omission.

The main objective for the crew once they arrived at Avondale Mills was to place two cars within the plant. This objective was realized once the last car had been placed. The conductor expressed relief that they had completed the job within their allowable hours of service. In the minds of the crewmembers, the only task remaining was to secure the equipment, retrieve their gear, and depart, which they did. The task of relining the main line switch was a necessary step in terms of safety and efficient train operations, but it was not part of the immediate job at hand. In other words, the crew forgot to reposition the switch, something that had been done many times before, because the primary objective (switching cars) had been achieved, and they had already begun to focus on the next task (securing the train and departing).

> Steps in which the item to be acted upon is concealed or lacking in conspicuity are liable to omission.

When the crew completed securing the train, the head end was about 342 feet from the main line switch. Both the engineer and the conductor said the switch banner was not visible at that point. Had the switch banner been conspicuous, it might have been detected by a crewmember who would likely have realized that the switch was not properly lined. And even though the switch position could have been detected as the crew passed along the adjacent road on the way to the terminal, they had no reason to observe it and apparently did not.

The Safety Board concludes that the crew of train P22 failed to reline the main line switch for one or more of the following reasons: (1) the task of relining the switch was functionally isolated from other tasks the crew was performing, (2) the crewmembers were rushing to complete their work and secure their train before reaching their hours-of-service limits, (3) the crew had achieved their main objective of switching cars and were focused on the next task of securing their equipment and going off duty, and (4) the switch was not visible to the crew as they worked, leaving them without a visual reminder to reline the switch.

The conductor stated that he did not hold a job briefing at the industry track that specifically addressed the switches at that location. Furthermore, he said that he did not tell the brakeman to ensure that the switch was lined and locked for the main track. NS rules require that a job briefing be held in this circumstance. Had a job briefing been held, it would likely have included a discussion of the switches and specifically who was responsible for ensuring that they were properly positioned. Had such a briefing taken place, the relining of the switch might not have been overlooked. The Safety Board concludes that had the conductor of train P22 held a comprehensive job briefing at the Avondale Mills industry track, as required by NS operating rules, the crew may have attended to the main line switch, and the accident may not have occurred.

After the accident, the FRA issued Safety Advisory 2005-01, which urged railroads to review their operating rules and take certain steps to ensure that crews using manually operated switches leave those switches in the proper position when their work is complete. The advisory referenced rules already implemented by the BNSF and UP railroads requiring that crews inform dispatchers of switch positions or inform them that switches had been properly relined before reporting clear of main line track. These rules were developed because of accidents similar to the one at Graniteville. The FRA also urged the use of a switch position reporting form to be filled out by the conductor before reporting clear of main line track.

While any operating rule change designed to enhance safety is welcomed, the Safety Board does not believe that rule changes or the use of forms is sufficient to prevent recurrences of accidents such as the one at Graniteville. The Safety Board notes that only 2 days after the Graniteville accident, a BNSF freight train was unexpectedly diverted into an industrial siding in California where it struck two loaded cars and derailed. This accident occurred less than 3 months after the BNSF implemented the rule referenced in the FRA advisory, a rule similar to those the FRA is urging other railroads to adopt and to the rules adopted by the NS after the accident. The Safety Board further notes that the UP had also adopted such a rule before the issuance of the advisory, but this did not prevent the September 15, 2005, collision of a southbound UP freight train with a standing local train in Shepherd, Texas, that resulted in a fatality and several injuries.

At Graniteville, the brakeman whose job it was to reline the switch said that he believed everything was correct when he left the scene, and there is no reason to believe that, even in his haste to return to the terminal, he would knowingly have left the switch improperly lined. While it is possible that a discussion with the dispatcher specifically regarding switches would have caused him to think through his actions and remember that he had neglected the switch, it is also possible that during such a discussion he would simply have confirmed his belief that he had left the site properly secured. He was certainly aware that when he cleared the track warrants with the dispatcher he was certifying that the main line was ready for use by other trains. He would not likely have done this if he had any doubt about how he had left the track. Finally, under normal conditions, the conductor would have cleared the track warrants with the dispatcher. He likely would have assumed that the brakeman had relined the switch and would have reported it to the dispatcher accordingly, especially if the brakeman had already departed.

Similarly, the use of forms, such as the switch position awareness form, has not been shown to be particularly effective in preventing railroad accidents. For example, some railroads, in order to lessen the chance that a traffic control signal will be missed or misinterpreted by a crew, require that conductors record signal indications as they are encountered en route. But the Safety Board has investigated a number of accidents in which such forms, although required and used, did not prevent crews from missing signals and causing accidents.

The FRA itself acknowledged the ineffectiveness of the safety advisory when, in October 2005, it issued Emergency Order 24 in response to a number of accidents involving improperly lined switches that occurred after promulgation of the advisory. While the Safety Board acknowledges the timeliness with which the FRA has addressed this safety issue, the Board is concerned about the effectiveness of the emergency order in preventing future accidents. The primary concern of the Board is that the emergency order largely requires what the previous safety advisory had recommended, which has been shown to be of questionable effectiveness.

For example, it is not likely that a railroad employee qualified and authorized to operate a hand-operated switch is unaware of the rules requiring that the switch be returned to its proper position after work is complete. It is therefore unclear how additional instruction on rules will improve employee performance. The emergency order also directs that an employee who operates a switch is responsible for returning it to its normal position; however, NS operating rules placed responsibility accordingly, and this did not prevent the Graniteville accident. The shortcomings of requiring the completion of a switch position awareness form and of requiring that switch positions be confirmed with the dispatcher have already been discussed. The additional operational tests required by the emergency order may be expected merely to confirm that employees know their responsibilities and that they fulfill those responsibilities most of the time. Such tests can perhaps prevent errors of ignorance, but not of omission.

The emergency order goes beyond the safety advisory recommendations and current regulations in at least two respects: by directing that job briefings be held at the completion of work and by requiring that a train crewmember who repositions a main line switch in non-signaled territory communicate with the engineer regarding the switch position. The Safety Board welcomes these requirements as worthy additions to existing requirements that could provide an additional layer of safety. As previously noted, a comprehensive safety briefing was not held before the work at Graniteville. Had such a briefing been held before and, more importantly, after the work (as required by the FRA emergency order), the accident might have been avoided.

A significant element of the emergency order is the provision for a civil penalty of up to $27,000 for violations of the order. The penalty may apply to the individual at fault and/or to the company or other corporate entity. The magnitude of this penalty reflects the seriousness with which the FRA views violations of this kind; however, it does not, in the view of the Safety Board, address the cause of the violations. That is, the Safety Board does not believe that employees forget to reline switches because the existing penalties are inadequate. Employees are acutely aware that an improperly lined switch, in addition to being a rule violation that could lead to removal from service, is likely to result in significant property damage or the injury or death of fellow employees or innocent bystanders. A substantial financial penalty is unlikely to be more effective than this sobering prospect in preventing these types of accidents.

Moreover, the Safety Board is concerned that the significant civil penalty may have an unintended impact on safety under some circumstances. That is, an employee who, after leaving a work site, realizes that a switch has been left improperly lined may be made more reluctant than in the past to immediately report the error to train dispatchers. The threat of the severe fine may prompt the employee to attempt a remedy (such as returning later to reline the switch) before the mistake can become known. As happened in the September 2005 fatal collision in Shepherd, Texas, such action on the part of the employee could contribute to an accident that might otherwise have been avoidable.

Clearly, measures beyond added or enhanced operating rules or additional forms, or even severe penalties, are needed to ensure that accidents such as the one at Graniteville do not recur. For example, a conspicuous visual stimulus associated with the switch at Graniteville might have alerted the P22 crew to the position of the main line switch despite any distractions.

A conspicuous visual stimulus could take one of many forms. It could be a steady or flashing strobe light (such as those used on some school buses and traffic signals) of a color that would not be confused with other railroad signals. This would be analogous to the "blue flag" procedures mandated by the FRA to draw particular attention when personnel are working on, under, or between rail cars. The crew would probably have seen a highly conspicuous light before leaving and would have relined the switch. Assuming they had tied down the train out of sight of the switch (and had not traveled past it in leaving) and had therefore left the switch improperly lined despite its conspicuity, a unique flashing strobe or other obvious light might have alerted the train 192 crew to the switch position in time to slow the train.

Alternatively, a device could be installed that would use electronic technology to draw the crew's attention to an improperly lined switch. Once an employee moved a switch to a non-normal position, the device could monitor the employee's proximity to the switch. Should the employee leave the vicinity without relining the switch, a notification could be sent to the employee's pager or cell phone. If the employee failed to respond within a specified time, the system could alert the railroad dispatcher or other designated railroad employee.

The foregoing examples represent two possible means, one visual and one electronic, of capturing an employee's attention, but the Safety Board recognizes that there are likely additional ways by which this objective could be achieved. The Safety Board therefore believes that the FRA should require that, along main lines in non-signaled territory, railroads install an automatically activated device, independent of the switch banner, that will, visually or electronically, compellingly capture the attention of employees involved with switch operations and clearly convey the status of the switch both in daylight and in darkness.

## Train Speeds in Non-Signaled Territory

The maximum authorized speed along the NS main line through Graniteville was 49 mph, and according to all available evidence, train 192 did not exceed this speed from the time it left Augusta until it reached Graniteville. However, sight distance tests demonstrated that the banner indicating the misaligned switch was not identifiable (by investigators who were specifically looking for it) until the train was within about 566 feet of the switch. To the crew of train 192, this distance might have been even less because of the other lights and signals within the train crew's visible range that may have created a perceptual conflict. The Safety Board concludes that at the speed train 192 was traveling as it entered Graniteville, the distance required for the train crew to perceive the banner of the misaligned switch, react to it, and bring the train to a safe stop was greater than the distance available.

The Safety Board was concerned as early as 1974 about the issue of train speeds in areas not under a form of centralized traffic control. As a result of its investigation of a fatal accident in Cotulla, Texas, involving a misaligned switch in non-signaled territory,[57] the Safety Board made the following safety recommendation to the Missouri Pacific Railroad (now part of the Union Pacific Railroad):

R-74-22

> Review your operation on main tracks that are not equipped with automatic block signals and take appropriate action to ensure the capability of engineers to stop trains in advance of misaligned switches. This action could include reducing the size or speed of trains, installing automatic block signals or advance-position indicators, or improving the visibility of switch stand targets.

This recommendation was classified "Closed—No Longer Applicable" after the Safety Board was provided with information indicating that the Missouri Pacific Railroad would continue to evaluate territories for the possible installation of automatic block signals or centralized traffic control.

At the time of the Cotulla accident, Interstate Commerce Commission (ICC) Order 29543 was in effect, which established a speed limit of "less than 50 mph" for freight trains operating in non-signaled territory.[58] The Safety Board's investigation of the Cotulla accident revealed that Order 29543 was inadequate in that the maximum allowable speed was established without consideration of factors, such as visibility and stopping distances, that at times may require lower speeds for safe operation. Therefore, the Safety Board made the following safety recommendation to the FRA:

R-74-26

> Determine and assess the current risks of train accidents involving misaligned switches, collisions, broken rail, and other route obstructions on main track where automatic block signal systems do not exist. Promulgate regulations to replace Interstate Commerce Commission Order 29543. These regulations should detail the major risks and controls assumed, set guidelines for safe operations below the maximum operating speed, and assign responsibility to the carrier for safe operations.

When the FRA issued regulations for signal and train control systems in January 1984, the wording of ICC Order 29543 was incorporated, unchanged, into the new regulations. The Safety Board had intended that the new regulations specify circumstances

[57] National Transportation Safety Board, *Collision of Missouri Pacific Railroad Company Freight Train Extra 615 South With a Standing Locomotive, Cotulla, Texas, December 1, 1973*, Railroad Accident Report NTSB/RAR-74/03 (Washington, D.C.: NTSB, 1974).

[58] This speed limit does not apply along non-signaled track where train movements are governed by a manual block system permanently in effect. See 49 *Code of Federal Regulations* 236.0(c).

that required that trains be operated below the allowable maximum speed. Because the FRA's actions did not satisfy the Safety Board's intent, Safety Recommendation R-74-26 was classified "Closed—Unacceptable Action."

As acknowledged by the FRA, the frequency and severity of accidents involving misaligned switches in non-signaled territory appear to be increasing. While at least some of the measures the FRA has directed through its emergency order may aid in reducing the number of switching mistakes, they are unlikely to eliminate such mistakes entirely. Additional measures are therefore needed to help ensure that such mistakes, when they do occur, do not result in accidents.

The Safety Board therefore believes that the FRA should require railroads, in non-signaled territory and in the absence of switch position indicator lights or other automated systems that provide train crews with advance notice of switch positions, to operate those trains at speeds that will allow them to be safely stopped in advance of misaligned switches.

## Hazardous Materials Release

During the derailment, the ninth car in the train, a tank car loaded with chlorine, was punctured. Emergency responders observed that the B-end coupler of the 11th car in the train, a car transporting steel coils, was in contact with the damaged tank jacket near the puncture in the tank shell and was covered with frost. Leaking chlorine, which boils at -29º F at atmospheric pressure, vaporizes rapidly from a liquid to a gas as it escapes through an opening such as a puncture, thereby freezing water vapor in the air and causing frost to form on nearby objects. Metallurgical examination of the damage on the shell around the puncture documented several impression marks on the shell that matched damage found on projecting surfaces of the coupler. The Safety Board therefore concludes that the chlorine gas release that occurred in this accident resulted when the shell of the 9th car on the train was punctured by the coupler of the 11th car.

Photographs show that the punctured tank car came to rest angled slightly to one side with the puncture opening extending below the midline of the resting tank. With the tank car in this position, it is likely that the liquefied chlorine above the level of the puncture was released within minutes and pooled on the ground. Measurements by emergency responders of the liquid level of the chlorine remaining in the tank on the day of the accident revealed that the tank car retained only about one-third of its original load of 180,000 pounds (13,830 gallons) of liquefied chlorine. Thus, approximately 120,000 pounds (9,218 gallons) of liquefied chlorine were released before the responders arrived on scene.

The liquefied chlorine rapidly vaporized and expanded when it spilled from the tank car. (The vaporization of liquefied chlorine at 32º F at atmospheric pressure can generate a gaseous cloud with a volume 450 times greater than the volume of the liquid released.[59]) As a result, the released chlorine created a large toxic cloud around the derailment site.

[59] Richard J. Lewis, Jr., *Hawley Condensed Chemical Dictionary-Thirteenth Edition*. New York: John Wiley & Sons, Inc., 1997.

Because gaseous chlorine is 2 1/2 times heavier than air, the toxic cloud tended to settle in low areas around the railroad tracks and remain more concentrated in these areas. Judging from the locations of the fatalities, the cloud likely expanded to the west and into the plant, followed the local topography running downhill to the south and west, and was blown to the north by light winds. All fatalities resulting from the accident were caused by inhalation of chlorine gas. Given that both train 192 crewmembers survived the collision (the engineer died later from exposure to the gas), no fatalities or serious injuries would have resulted from this accident had a tank car of chlorine not been punctured.

## Tank Car Performance

### *Tank Car Crashworthiness*

As previously noted, the 9th of 42 cars in the train was struck and punctured by the coupler of the 11th car transporting steel coils. The combined weight of the striking steel coil car and the rest of the trailing cars in the train was about 2,618 tons. The estimated impact speed was determined to be about 42 mph. This combination of mass and velocity subjected the punctured chlorine tank car to severe impact forces during the derailment, with the most concentrated forces being applied in the area struck by the coupler.

The punctured tank car was built in 1993, and therefore was required to have both the tank heads and the tank shell constructed of normalized steel. The normalizing heat treatment typically increases the fracture toughness and lowers the ductile-to-brittle transition temperature of steel plate. Thus, for a given composition of steel, normalized steel is less susceptible to catastrophic brittle fractures and requires more energy to fracture than non-normalized steel.

Charpy impact testing showed that the normalized steel in the tank shell of the punctured chlorine car had a fracture toughness that was significantly greater than the fracture toughness of the non-normalized steels of the catastrophically ruptured tank cars involved in the derailment of a Canadian Pacific Railway freight train in Minot, North Dakota, in January 2002.[60] The steel in the Minot tank cars exhibited relatively low fracture toughness, and cracks propagated rapidly around the circumference of each tank. The higher fracture toughness in the Graniteville tank car contributed to the relatively quick arrest of the crack even though there was brittle fracture in its outer portions.

Chlorine tank cars such as the punctured ninth car are tested to a pressure of 500 psig compared to a test pressure of 300 psig for tank cars used to transport anhydrous ammonia and liquefied petroleum gas. To be rated for the increased operating pressure, the tanks of chlorine tank cars must have greater tank wall thicknesses than tanks of the lower pressure cars. Because of the improved properties of normalized steel and the increased wall thickness, the

[60] National Transportation Safety Board, *Derailment of Canadian Pacific Railway Freight Train 292-16 and Subsequent Release of Anhydrous Ammonia Near Minot, North Dakota, January 18, 2002*, Railroad Accident Report NTSB/RAR-04/01 (Washington, D.C.: NTSB, 2004).

punctured car was among the strongest tank cars currently in service. The Safety Board therefore concludes that, as shown in the Graniteville accident, even the strongest tank cars in service can be punctured in accidents involving trains operating at moderate speeds.

The Safety Board addressed the improvement of crashworthiness of railroad tank cars in its Minot, North Dakota, accident report. The Board stated in its report:

> Improvements in the crashworthiness of pressure tank cars can be realized through the evaluation of alternative steels and tank car performance standards. The ultimate goal of this effort should be the construction of railroad tank cars that have sufficient impact resistance and that eliminate the risk of catastrophic brittle failures under all operating conditions and in all environments. Achieving such a goal does not necessarily require the construction of a tank car that is puncture–proof; it may only require construction of a car that will remain intact and slowly leak its contents if it is punctured.

To address these concerns, the Board recommended that the FRA:

R-04-6

Validate the predictive model the Federal Railroad Administration is developing to quantify the maximum dynamic forces acting on railroad tank cars under accident conditions.

R-04-7

Develop and implement tank car design-specific fracture toughness standards, such as minimum average Charpy value, for steels and other materials of construction for pressure tank cars used for transportation of U.S. Department of Transportation class 2 [gases] hazardous materials, including those in low-temperature service. The performance criteria must apply to the material orientation with the minimum impact resistance and take into account the entire range of operating temperatures of the tank car.

On August 9, 2004, the FRA responded and described the actions being taken to address each recommendation. In response to Safety Recommendation R-04-6, the FRA stated that it has identified ongoing programs at the Volpe National Transportation Systems Center and the University of Illinois at Chicago to evaluate in-train forces associated with train derailments. The FRA said it anticipates that the modeling program will be completed in early 2006. Regarding Safety Recommendation R-04-7, the FRA stated that further research in this area is required and that it may require a "three-year effort" to develop adequate tank car design-specific fracture toughness standards.

On June 22, 2005, in addressing the FRA's response to Safety Recommendation R-04-6, the Safety Board noted that programs to analyze in-train forces have already been identified and that it expects validation of the models to be a standard part of any model development. Based on FRA's response, Safety Recommendation R-04-6 was classified "Open—Acceptable Response." In addressing the FRA's response to Safety Recommendation R-04-7, the Safety Board stated that implementation of tank car design-specific fracture toughness standards, such as Charpy impact value, can be achieved for standard manufacturing processes without waiting for the results of the modeling effort associated with Safety Recommendation R-04-6. The Safety Board added that evaluation and analysis of the dynamics of the Minot accident can provide data about the levels of fracture toughness that may be necessary for pressure tank cars and that data from subsequent accidents in Macdona, Texas, on June 28, 2004, and Graniteville will provide additional information. Based on the FRA's response, Safety Recommendation R-04-7 was classified "Open—Unacceptable Response."

Congress also recognized the significance of the Safety Board's safety recommendations to the FRA by incorporating them into the "Safe, Accountable, Flexible, Efficient Transportation Equity Act," which was signed into law in August 2005. Section 20155 of the act stipulated that the FRA was to validate the predictive model within 1 year of enactment and initiate a rulemaking to implement appropriate design standards for tank cars within 18 months of enactment.

The Macdona and Graniteville accidents, both of which have occurred since the Minot report was issued, resulted in the puncturing of two chlorine tank cars and the death of 12 people from chlorine inhalation. When a liquefied gas such as chlorine, which is poisonous by inhalation, is released, large clouds at lethal concentrations can be generated within minutes. There is often little or no time to alert citizens and to take effective action. Based on AAR data on tank car shipments in the United States for 2002, chlorine and anhydrous ammonia ranked as, respectively, the fourth and seventh most commonly shipped hazardous materials by tank car. Furthermore, these products routinely travel through communities of varying size, including large metropolitan areas.

### *Reduction of Tank Car Vulnerability*

It is the belief of the Safety Board that modeling of accident forces and the application of fracture toughness standards as recommended in the Minot report will provide the most effective improvements in the crashworthiness of tank cars. However, at best, it will be several years before a significant percentage of pressure tank cars in service will have been so designed and constructed. Therefore, the most expedient and effective means to reduce the public risk from the release of highly poisonous gases in train accidents is for railroads to implement operational measures that will minimize the vulnerability of tank cars transporting these products.

Supplemental operational measures are already imposed for the transportation of certain high-risk materials. For example, the DOT's Pipeline and Hazardous Materials Safety Administration requires that pipeline operators have an integrity management plan for high-consequence areas, which are identified on the basis of population densities and environmentally sensitive areas. The regulations are designed to identify high-risk areas and to develop a process for evaluating the risks within areas identified as high-consequence.[61]

[61] Under the regulations, a high-consequence area may include an urban area with a population greater than 50,000, or a population density of 1,000 people per square mile, or other area (an unincorporated town or village, for example) that contains a concentrated population.

The integrity management plan for pipeline operators describes both preventive and mitigative measures that a pipeline operator must take to protect a high-consequence area. Such measures include implementing enhanced damage prevention practices, better monitoring, shorter inspection intervals, improved system monitoring and detection, and additional personnel training/drills with emergency responders.

For rail transportation of hazardous materials, the AAR since 1990 has published Circular No. OT-55, *Recommended Railroad Operating Practices for Transportation of Hazardous Materials*. This circular contains recommended operating practices for member railroads that include speed restrictions for "key trains" and enhanced track inspection standards for "key routes."[62] Because the train involved in the Graniteville accident was not a key train and the main line track was not on a key route, neither the operational restrictions nor additional inspections applied. Further, even if train 192 had met the definition of a key train, Circular No. OT-55 would not have restricted its speed below that at which it was already operating.

Two research studies have also been conducted that address operational measures to reduce the vulnerability of tank cars transporting hazardous materials. The 1992 FRA report, *Hazardous Materials Car Placement in a Train Consist*,[63] concluded that the rear one-quarter of a train is the most desirable location for cars containing hazardous materials and that reducing the speed and size of trains can reduce the number of cars derailed in an accident. The second study, "Minimizing Derailments of Railcars Carrying Dangerous Commodities Through Effective Marshaling Strategies,"[64] prepared for the Transportation Research Board, reached similar conclusions and provided some additional statistical information to validate those conclusions.

Both these reports address operational measures that might have made a difference in the Graniteville accident. Placement of the three tank cars transporting chlorine near the front of the train and ahead of most of the trailing tonnage increased the probability that the cars would be damaged and would release chlorine in an accident. Had the chlorine cars been placed behind the other loaded cars in the train, the reduction in the trailing tonnage would have reduced the impact forces on the tank cars. A reduction in train speed would also have significantly reduced the derailment forces on the tank cars. These operational measures, taken individually or collectively, may have been sufficient to prevent the puncture of the tank car and the release of the chlorine.

While the FRA report notes that car placement might be detrimental to train handling and dynamics and that switching cars to change their order in the train might

[62] Under the recommended practices, a key train includes any train with five tank car loads of poison inhalation hazard (PIH) cargo; or 20 carloads of a combination of PIH, flammable gas, explosives, and environmentally sensitive chemicals; or one or more carloads of high-level radioactive waste. A key train cannot exceed 50 mph.

[63] R. E. Thompson, E. R. Zamejc, and D. R. Ahlbeck, *Hazardous Materials Car Placement in a Train Consist, Vol. 1 (Review and Analysis).* Report DOT/FRA/ORD/18.I. Federal Railroad Administration, U.S. Department of Transportation (Washington, D.C., 1992).

[64] F. F. Saccomanno and S. El-Hage, "Minimizing Derailments of Railcars Carrying Dangerous Commodities Through Effective Marshaling Strategies," *Transportation Research Record* 1245. Transportation Research Board, National Research Council (Washington, D.C., 1989).

result in exposing these cars to additional dangers, railroads should be able to take these factors into account and still reduce the vulnerability of tank cars transporting chlorine, anhydrous ammonia, and other liquefied gases that are poisonous by inhalation. Given the risks involved in the transportation of such liquefied gases, the Safety Board believes that the FRA should require that railroads implement operating measures, such as positioning tank cars toward the rear of trains and reducing speeds through populated areas, to minimize impact forces from accidents and reduce the vulnerability of tank cars transporting chlorine, anhydrous ammonia, and other liquefied gases designated as poisonous by inhalation.

## Train Crew Protection From Inhalation Hazards

The Safety Board has found that freight train crews may survive collisions and derailments only to be injured or killed by hazardous materials released in the accident. Although the crew of NS train 192 survived the collision and exited the locomotive unassisted, they could not escape exposure to the chlorine gas. The conductor said that after getting out of the locomotive, he and the engineer were able to walk some distance from the collision site. The two were transported to hospitals. The conductor was treated and released; the engineer died several hours later from inhalation of the toxic gas.

The consequences of this accident are remarkably similar to those of the June 28, 2004, collision of two freight trains near Macdona, Texas. A tank car on the striking train was punctured and released chlorine gas. Once again, the crew of the striking train survived the collision and exited the locomotive unassisted into a chlorine-laden atmosphere. The conductor and engineer had walked about 1,400 feet away from the collision site when the conductor collapsed and died from exposure to chlorine gas. The engineer was hospitalized with severe injuries due to his exposure.

Emergency breathing apparatus is commercially available that would give crewmembers in these circumstances an opportunity to escape a hazardous atmosphere. According to the manufacturers, many of these devices are approved for use to escape certain chemical atmospheres, including chlorine and ammonia, as well as fire and smoke. Emergency escape breathing devices are typically effective for a period of time (5 to 50 minutes) that allow the user to escape and reach a safe location. The devices are used in a variety of industrial settings. They must also be carried on merchant and passenger vessels under the Safety of Life at Sea protocols. The Safety Board concludes that had the engineer of train 192 been wearing appropriate, fully functioning emergency escape breathing apparatus when he walked away from the collision site, he may not have succumbed to the effects of chlorine gas inhalation.

The Safety Board therefore believes that the FRA should determine the most effective methods of providing emergency escape breathing apparatus for all crewmembers on freight trains carrying hazardous materials that would pose an inhalation hazard in the event of unintentional release, and then require railroads to provide these breathing apparatus to their crewmembers along with appropriate training.

# Conclusions

## Findings

1. Neither train equipment defects nor track condition were causal or contributory to this accident.

2. In regard to the crew of train 192, fatigue, crew training and qualifications, and drugs and alcohol were not factors in this accident.

3. In regard to the crew of train P22, neither crew qualifications and training nor fatigue were causal or contributory to this accident, and no evidence was found to suggest drug or alcohol use.

4. The execution of the emergency response to this accident was timely, appropriate, and effective.

5. The crew of train P22 failed to reline a main line switch after using it, leading to the subsequent and unexpected diversion of train 192 into an industry track where it struck train P22 and derailed.

6. The crew of train P22 failed to reline the main line switch for one or more of the following reasons: (1) the task of relining the switch was functionally isolated from other tasks the crew was performing, (2) the crewmembers were rushing to complete their work and secure their train before reaching their hours-of-service limits, (3) the crew had achieved their main objective of switching cars and were focused on the next task of securing their equipment and going off duty, and (4) the switch was not visible to the crew as they worked, leaving them without a visual reminder to reline the switch.

7. Had the conductor of train P22 held a comprehensive job briefing at the Avondale Mills industry track, as required by Norfolk Southern operating rules, the crew may have attended to the main line switch, and the accident may not have occurred.

8. At the speed train 192 was traveling as it entered Graniteville, the distance required for the train crew to perceive the banner of the misaligned switch, react to it, and bring the train to a safe stop was greater than the distance available.

9. The chlorine gas release that occurred in this accident resulted when the shell of the 9th car on the train was punctured by the coupler of the 11th car.

10. As shown in the Graniteville accident, even the strongest tank cars in service can be punctured in accidents involving trains operating at moderate speeds.

11. Had the engineer of train 192 been wearing appropriate, fully functioning emergency escape breathing apparatus when he walked away from the collision site, he may not have succumbed to the effects of chlorine gas inhalation.

## Probable Cause

The National Transportation Safety Board determines that the probable cause of the January 6, 2005, collision and derailment of Norfolk Southern train 192 in Graniteville, South Carolina, was the failure of the crew of Norfolk Southern train P22 to return a main line switch to the normal position after the crew completed work at an industry track. Contributing to the failure was the absence of any feature or mechanism that would have reminded crewmembers of the switch position and thus would have prompted them to complete this final critical task before departing the work site. Contributing to the severity of the accident was the puncture of the ninth car in the train, a tank car containing chlorine, which resulted in the release of poisonous chlorine gas.

# Recommendations

As a result of its investigation of the January 6, 2005, collision and derailment of Norfolk Southern train 192 in Graniteville, South Carolina, the National Transportation Safety Board makes the following safety recommendations:

**To the Federal Railroad Administration:**

> Require that, along main lines in non-signaled territory, railroads install an automatically activated device, independent of the switch banner, that will, visually or electronically, compellingly capture the attention of employees involved with switch operations and clearly convey the status of the switch both in daylight and in darkness. (R-05-14)
>
> Require railroads, in non-signaled territory and in the absence of switch position indicator lights or other automated systems that provide train crews with advance notice of switch positions, to operate those trains at speeds that will allow them to be safely stopped in advance of misaligned switches. (R-05-15)
>
> Require railroads to implement operating measures, such as positioning tank cars toward the rear of trains and reducing speeds through populated areas, to minimize impact forces from accidents and reduce the vulnerability of tank cars transporting chlorine, anhydrous ammonia, and other liquefied gases designated as poisonous by inhalation. (R-05-16)
>
> Determine the most effective methods of providing emergency escape breathing apparatus for all crewmembers on freight trains carrying hazardous materials that would pose an inhalation hazard in the event of unintentional release, and then require railroads to provide these breathing apparatus to their crewmembers along with appropriate training. (R-05-17)

## BY THE NATIONAL TRANSPORTATION SAFETY BOARD

**MARK V. ROSENKER**
Acting Chairman

**ELLEN ENGLEMAN CONNERS**
Member

**DEBORAH A. P. HERSMAN**
Member

**Adopted: November 29, 2005**

# Appendix A

## Investigation

The National Response Center notified the National Transportation Safety Board of the accident about 4:15 a.m. on January 6, 2005. The investigator-in-charge and other members of the Safety Board investigative team were launched from the Washington, D.C., headquarters office and from the Atlanta, Georgia, field office. Investigative groups were established to study operations, track, signals, mechanical, survival factors, human performance, and hazardous materials issues. No hearings or depositions were held in conjunction with this accident. Member Deborah A. P. Hersman was the Board Member on scene.

Parties to the investigation included the Federal Railroad Administration, Norfolk Southern Railway Company, the Brotherhood of Locomotive Engineers and Trainmen, the United Transportation Union, General American Transportation, Union Tank Car Company, Trinity Industries, Olin Corporation, the Graniteville, Vaucluse, and Warrenville Volunteer Fire Department, and the Aiken County Sheriff's Office.

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