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

PB2004-916301
Notation 7461A

National
Transportation
Safety Board
Washington, D.C.

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Adopted March 9, 2004

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

National Transportation Safety Board. 2004. ***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, DC.**

Abstract: At approximately 1:37 a.m. on January 18, 2002, Canadian Pacific Railway freight train 292-16 derailed 31 of its 112 cars about 1/2 mile west of the city limits of Minot, North Dakota. Five tank cars carrying anhydrous ammonia catastrophically ruptured, and a vapor plume covered the derailment site and surrounding area. One resident was fatally injured, 11 people sustained serious injuries, and 322 people, including the 2 train crewmembers, sustained minor injuries. Damages exceeded $2 million, and more than $8 million has been spent for environmental remediation.

The major safety issues identified in this accident are Canadian Pacific Railway's programs and practices for the inspection and maintenance of joint bars in its continuous welded rail; the Federal Railroad Administration's oversight of continuous welded rail maintenance programs; and tank car crashworthiness, specifically the adequacy of non-normalized steels to resist tank fracture propagation. The analysis also addresses the appropriateness of using shelter-in-place to protect the public from the release of hazardous material.

As a result of its investigation of this accident, the Safety Board makes safety recommendations to the Federal Railroad Administration and the Canadian Pacific Railway.

Contents

Executive Summary

At approximately 1:37 a.m. on January 18, 2002, eastbound Canadian Pacific Railway freight train 292-16, traveling about 41 mph, derailed 31 of its 112 cars about 1/2 mile west of the city limits of Minot, North Dakota. Five tank cars carrying anhydrous ammonia, a liquefied compressed gas, catastrophically ruptured, and a vapor plume covered the derailment site and surrounding area. The conductor and engineer were taken to the hospital for observation after they complained of breathing difficulties. About 11,600 people occupied the area affected by the vapor plume. One resident was fatally injured, and 60 to 65 residents of the neighborhood nearest the derailment site were rescued. As a result of the accident, 11 people sustained serious injuries, and 322 people, including the 2 train crewmembers, sustained minor injuries. Damages exceeded $2 million, and more than $8 million has been spent for environmental remediation.

The National Transportation Safety Board determines that the probable cause of the derailment of Canadian Pacific Railway train 292-16 was an ineffective Canadian Pacific Railway inspection and maintenance program that did not identify and replace cracked joint bars before they completely fractured and led to the breaking of the rail at the joint. Contributing to the severity of the accident was the catastrophic failure of five tank cars and the instantaneous release of about 146,700 gallons of anhydrous ammonia.

The safety issues identified in this accident were as follows:

- Canadian Pacific Railway's programs and practices for the inspection and maintenance of joint bars in its continuous welded rail;
- The Federal Railroad Administration's oversight of continuous welded rail maintenance programs;
- Tank car crashworthiness, specifically the adequacy of non-normalized steels to resist tank fracture propagation.

The analysis also addresses the appropriateness of using shelter-in-place to protect the public from the release of hazardous material.

As a result of its investigation of this accident, the Safety Board makes safety recommendations to the Federal Railroad Administration and the Canadian Pacific Railway.

Factual Information

Accident Synopsis

At approximately 1:37 a.m.[1] on January 18, 2002, eastbound Canadian Pacific Railway (CPR) freight train 292-16, traveling about 41 mph, derailed 31 of its 112 cars about 1/2 mile west of the city limits of Minot, North Dakota. (See figure 1.) Five tank cars carrying anhydrous ammonia, a liquefied compressed gas,[2] catastrophically ruptured, and a vapor plume covered the derailment site and surrounding area. The conductor and engineer were taken to the hospital for observation after they complained of breathing difficulties. About 11,600 people occupied the area affected by the vapor plume.[3] One resident was fatally injured, and 60 to 65 residents of the neighborhood nearest the derailment site were rescued. As a result of the accident, 11 people sustained serious injuries, and 322 people, including the 2 train crewmembers, sustained minor injuries. Damages exceeded $2 million, and more than $8 million has been spent for environmental remediation.

Figure 1. Looking southwest at accident scene.

[1] All times are central standard time unless otherwise noted.

[2] Under international standards, anhydrous ammonia is classified as a poisonous gas by inhalation. Under the U.S. Department of Transportation Hazardous Materials Regulations, anhydrous ammonia is classified as a non-flammable, non-poisonous gas that is also an “inhalation hazard.”

[3] The chief of the Minot Rural Fire Department superimposed a dispersion model developed by CPR contractors over a map of the City of Minot; the plume covered one-third of the population of approximately 35,000.

Accident Narrative

On January 14 and 15, 2002, Canadian Fertilizers Limited loaded between 29,000 and 29,800 gallons of anhydrous ammonia into each of 15 tank cars in Medicine Hat, Alberta, Canada. At Medicine Hat, the 15 loaded cars were added to train 292-16, which had departed South Edmonton on January 16, 2002, bound for St. Paul, Minnesota.

On Thursday January 17, 2002, at 9:15 p.m., a train crew consisting of an engineer and conductor went on duty at Portal, North Dakota, to take train 292-16 to Harvey, North Dakota. (See figure 2.) The train consisted of 2 locomotives, 86 loads, and 26 empties. Its gross weight was 12,342 tons, and it was 7,138 feet long. The train consist included 39 tank cars containing hazardous materials as regulated and defined by the U.S. Department of Transportation (DOT), including the 15 car loads of anhydrous ammonia, 10 car loads of liquid petroleum gas, 11 car loads of styrene monomer, and 3 empty tank cars that contained residue of a DOT-regulated hazardous material. (See appendix C for a complete consist of train 292-16.)

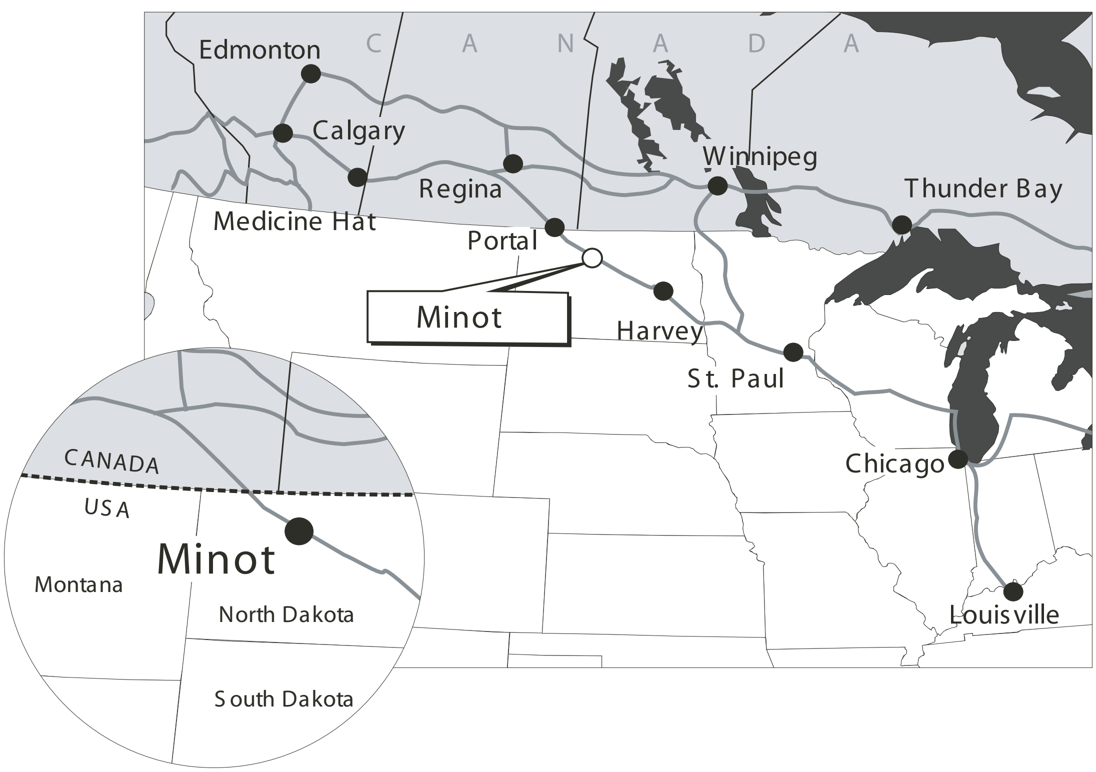

Figure 2. Map of train's route and derailment location.

About 4 1/2 hours into the trip, the engineer prepared to slow the train from 41 mph[4] for a speed restriction of 20 mph at milepost (MP) 470.1 by changing the controls

[4] According to the event recorder from the lead locomotive.

from power to dynamic braking. At that time, the crewmembers said, they noticed the train traversing a rough spot.[5] The conductor said he told the engineer to "bring her to a controllable stop." The engineer said he reached for the handle to apply the brakes lightly, and as he began to manipulate the controls, the train's emergency brakes automatically applied.[6]

Immediately after the emergency stop, the train crew discovered that there had been a significant derailment beginning with the fourth car behind the locomotives. The conductor told investigators, "…I had watched the explosions and the arcs from our train and the plumes of smoke that came up with the explosions. I knew there were explosions because I felt the concussion and I heard it." Additionally, the derailing equipment had knocked down power lines, disrupting electrical power to 2,820 residences and businesses in the nearby area. It would later be determined that 31 cars had derailed, including all 15 tank cars of anhydrous ammonia. (See figures 3 and 4.) The remaining hazardous materials cars were farther back in the train and were not involved in the derailment.

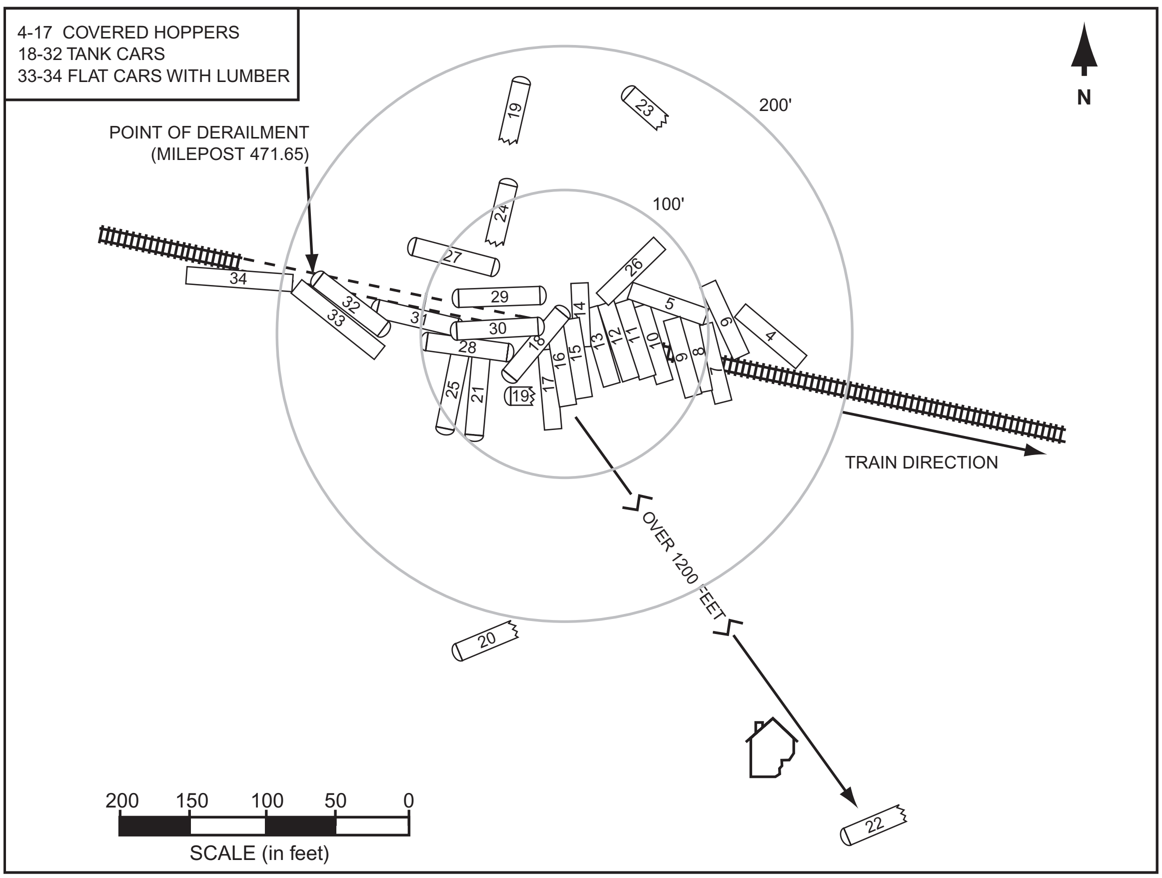

Figure 3. Wreckage.

[5] This "rough spot" was later determined to be at or near a rail joint in the north rail, which will be discussed in more detail later in this report.

[6] The emergency brakes applied when the air brake line that extends the length of the train separated as cars began to derail.

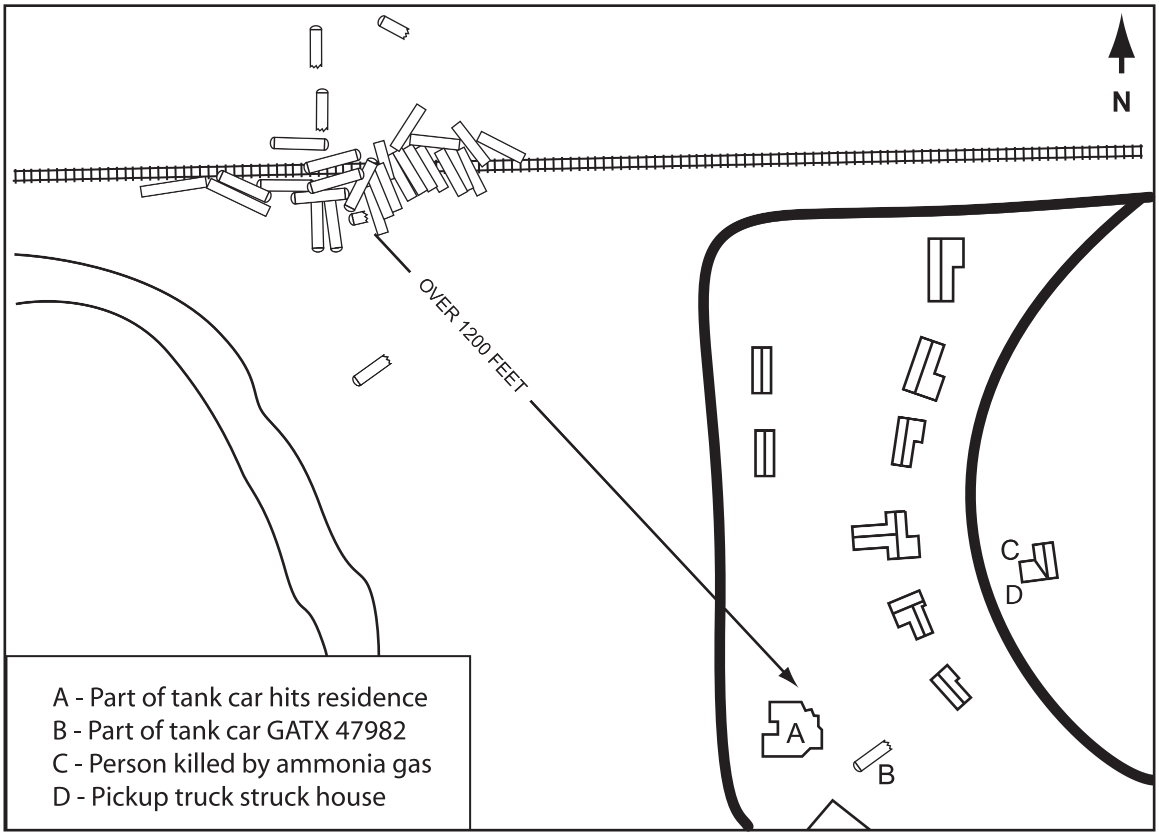

Figure 4. Detail of wreckage and Tierracita Vallejo neighborhood.

The conductor stated that immediately after the derailment, he repeatedly called out "emergency" on the radio, as required by the operating rules. The conductor also radioed the CPR dispatcher in Minneapolis, Minnesota. While awaiting a response from the dispatcher, he called 911 in Minot on his personal cell phone at about 1:37 a.m. and reported his train's location and the fact that the train had derailed with an explosion and hazardous materials release. The engineer used his personal cell phone to call the CPR yard office in Harvey, North Dakota, to report the same information to the railroad. When the dispatcher in Minneapolis contacted the crew, they told him that the train had derailed and they could see "vapors or something."

The engineer and conductor decided to evacuate the area using the train's locomotives. The crew asked for and received permission from the dispatcher to detach the locomotives and pull away from the train. According to the dispatcher's Record of Movement of Trains, at 1:43 a.m., a crewmember told the dispatcher that something "… smells like anhydrous ammonia there at the head end at milepost 471." The conductor then walked to the rear locomotive and uncoupled it from the train. He stated that at that time, he was in the middle of a white ammonia cloud. The conductor then went back to the lead locomotive and told the engineer to continue east toward Minot. The crew departed the area using the locomotives.

Hazardous Material Release

During the derailment, five anhydrous ammonia tank cars, GATX 47814 (car 19[7]), GATX 47837 (car 20), GATX 47982 (car 22), GATX 48081 (car 23), and PLMX 4504 (car 24) sustained catastrophic shell fractures that resulted in the separation of the tank shells and the complete and instantaneous loss of the contents. When the tanks violently ruptured, sections of the fractured tanks were propelled as far as 1,200 feet from the tracks. About 146,700 gallons of anhydrous ammonia were released from the five cars, and a cloud of hydrolyzed ammonia formed almost immediately. This plume rose an estimated 300 feet[8] and gradually expanded 5 miles downwind of the accident site and over a population of about 11,600 people.

Over the next 5 days, another 74,000 gallons of anhydrous ammonia were released from six other anhydrous ammonia tank cars, PLMX 4644 (car 18), GATX 49248 (car 21), GATX 58659 (car 25), GATX 49285 (car 26), GATX 48004 (car 28), and GATX 48103 (car 31).

Emergency Response

Timeline[9]

Upon receiving the 1:37 a.m. call from the conductor, the Ward County 911 dispatcher immediately paged the Minot Rural Fire Department.[10] The fire department chief responded directly to the scene from his house (approximately 2 miles away); the assistant chief responded directly to the Minot Rural Fire Department fire hall. Six fire department units responded from the fire hall to the scene (approximately 6 miles away).

At 1:44 a.m., the Minot Rural Fire Department requested mutual aid from the Minot City and Burlington Fire Departments.

At 1:47 a.m., the chief of the Minot Rural Fire Department arrived on-scene at the West 83 Bypass at the intersection of 4th Avenue NW (approximately 1/2 mile east and 1/2 mile north of the train derailment site). He immediately assumed incident command and performed an initial site and accident assessment. At approximately 1:50 a.m., the chief established a field incident command post along the West 83 Bypass near the intersection of 19th Avenue NW. (See figure 5.)

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[7] The cars in CPR train 292-16 are numbered in order; the first car behind the locomotives is car number 1.

[8] Local weather stations at Bismarck, North Dakota, reported a temperature inversion in the area at the time of the accident. The low ground temperatures helped to keep the ammonia plume close to ground level as it traveled downwind.

[9] See appendix B for a complete timeline of the accident. Appendix D details the units that responded to the emergency.

[10] The Minot Rural Fire Department is a volunteer fire department of 30 volunteers, including the chief, that serves 5,600 people.

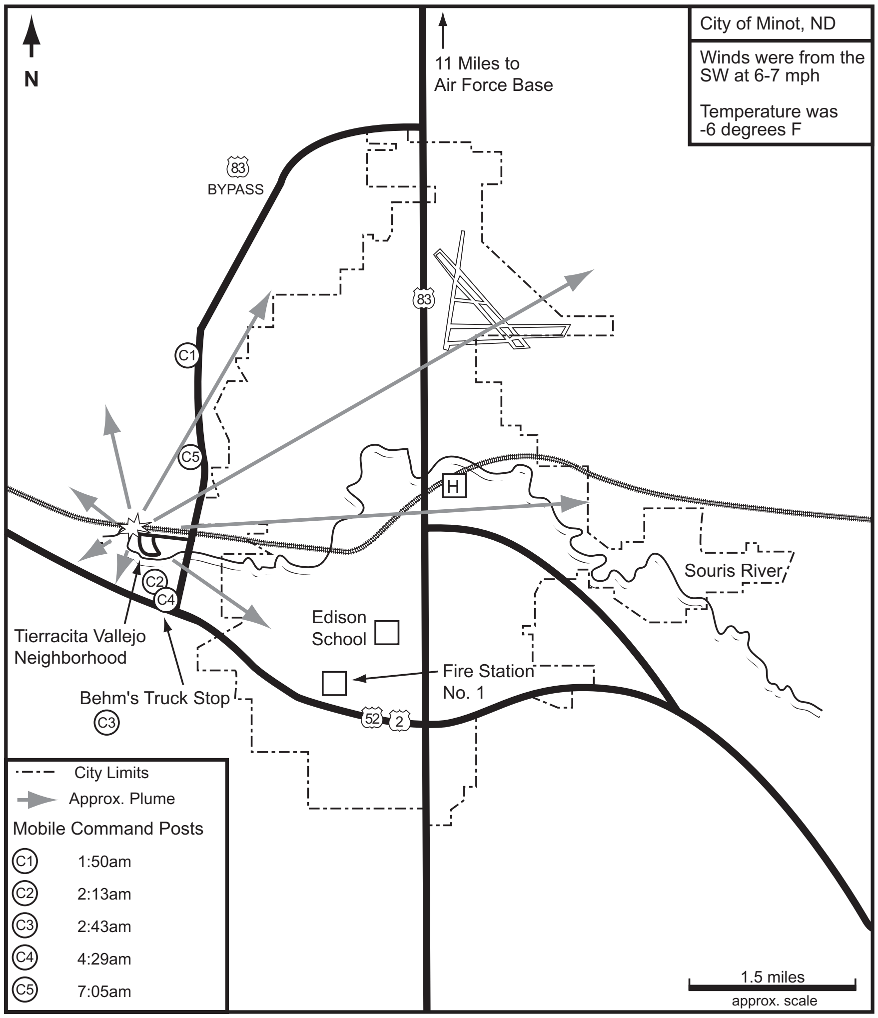

Figure 5. Map of derailment area.

Meanwhile, the crew of CPR train 292-16 was traveling east, away from the derailment site, with the two locomotives. At 1:47 a.m., near the Arrowhead grade crossing (at 16th Street and approximately 2nd Avenue SW), the crew met a Minot City Fire Department battalion chief waiting at the crossing. The battalion chief was responding to a different call at the time, but when the train crew approached him on foot and told him about the derailment, he notified the Minot City Fire Department and went toward the derailment location.

The conductor and engineer remained at the crossing and prevented entry to the area by private vehicles. They were later relieved by law enforcement personnel, and they were transported by car to Minot City Fire Station Number 1. At the fire station, the crew provided all of the train paperwork, including information about the train's hazardous cargo. They also described the ammonia fog at the derailment site. The two crewmembers were then transported to Minot Trinity Hospital for observation and treatment.

According to interviews and 911 records, immediately after the accident, two residents of Tierracita Vallejo, the neighborhood closest to the derailment, went outside their homes, became disoriented, and were unable to get back to their homes for some time. When one of these residents did return to his home, he and his wife drove their car away from the neighborhood. Another couple attempting to flee their home in their truck crashed the vehicle into a house diagonally across the street. The occupants of the house were able to assist the female passenger into the house, but the male driver collapsed in their yard, and they were unable to move him. At approximately 2:06 a.m., one of the occupants of the house called Ward County 911 to report the man on the ground outside the house. The 911 operator told the resident that emergency responders were in the area, but in the meantime, residents must take precautions.

At 2:09 a.m., an initial staging area was set up at the West 83 Bypass near 21st Avenue NW. Because of the vapor plume, responding units were directed to travel around the city of Minot to reach the north side of the accident.

At 2:13 a.m., the Minot Rural Fire Department requested that the Burlington Fire Department come to Behm's Truck Stop just west of the 83 Bypass along Highways 2 and 52 (southwest of the derailment location). At 2:23 a.m., State Radio paged Des Lacs and Berthold Fire Departments to request mutual aid assistance.

At 2:37 a.m., the emergency operations center was opened at the Minot City Fire Station Number 1. At that time, Minot Rural Fire Department engine 214 was assigned as the mobile command unit, a Minot Rural Fire Department assistant chief was assigned as the on-scene incident commander, and the Minot Rural Fire Department chief maintained command at the emergency operations center.

At 2:39 a.m., two firefighters who were driving Minot Rural Fire Department tanker 212 drove through the vapor cloud when the wind shifted. The firefighters reported their eyes watering a minute later. At 2:40 a.m., Minot Rural Fire Department engines 214 and 216 staged at 21st Avenue NW, and Minot Rural Fire Department unit 218 reported that all the civilians that had been encountered on the local roads were assembled inside Behm's Truck Stop.

By 2:42 a.m., the vapor cloud was reported to cover the Highway (Routes) 2/5/83 Bypass completely. At 2:43 a.m., the mobile command post was repositioned on a hill farther south of the derailment. At 2:45 a.m., a decision was made to evacuate the people at Behm's Truck Stop. At 2:52 a.m., a city bus was sent to Behm's Truck Stop to take the people outside the affected area.

As early as 1:41 a.m., 911 operators were telling residents to stay in their homes and close their windows. By the time the emergency operations center was opened at 2:37 a.m., emergency responders, because of the ammonia vapor cloud and the dangers it posed to the residents of both the Tierracita Vallejo neighborhood close to the derailment and to the city of Minot, had decided not to evacuate residents. This response, called "sheltering-in-place," differs from an evacuation in that people who shelter-in-place take precautions but remain within the "hot zone."[11] The emergency responders then issued additional guidelines and implemented the public notification procedures by contacting the local media and sounding the outdoor warning system.

At approximately 3:40 a.m., Edison Elementary School was opened as an emergency shelter and triage area for residents of Minot.

At 4:29 a.m., the Minot Rural Fire Department relocated the staging area for rescue operations to Behm's Truck Stop where the levels of ammonia had diminished. This located the staging area near the affected neighborhood.

At approximately 4:39 a.m., the resident who had called 911 about the man on the ground outside his house called a second time to report that the man was still outside and that the man's wife, who had been outside in the cloud, was in poor condition. The resident explained that there was no cloud around the house at the time. At 4:47 a.m., Minot Rural Fire Department unit 219 went into the Tierracita Vallejo neighborhood to rescue the residents. This first unit into the area found the man, but in attempting to recover him, the firefighters exited their unit without first donning their self-contained breathing apparatus (SCBA). They were unable to recover the injured man and had to leave the scene and regroup at the staging area.

At approximately 5:07 a.m., the residents of the house and the wife of the injured man had gone to Behm's Truck Stop, and emergency responders returned to pick up the injured man. At approximately 5:15 a.m., the assistant chief of the Minot Rural Fire Department, wearing a SCBA, found the man lying on the driveway. Ten minutes later, the Burlington Fire Department transported the man to Behm's Truck Stop, where he was assessed by responders from Community Ambulance and found to be unresponsive.

At about 5:30 a.m., firefighters entered the Tierracita Vallejo neighborhood and went door-to-door removing residents from their homes and putting them on Minot City buses. The residents were then transported to a triage area near Behm's Truck Stop. By this time, some of them were able to leave the area in their own vehicles. At 6:41 a.m., the firefighters continued their rescue efforts as the ammonia odor continued to permeate. By 8:21 a.m., after a second check of all the houses to ensure no one was left behind, the rescue operation in the neighborhood was complete. The chief estimated that between 60 and 65 residents of Tierracita Vallejo were rescued.

In the afternoon of January 18, 2002, the shelter and triage area at Edison Elementary School was closed, as was Minot Rural Fire Department's field command post. At 10:00 a.m. on January 20, 2002, the Minot Rural Fire Department chief relocated the emergency operations center to the Minot Municipal Auditorium. The fire department remained on scene until 2:00 a.m. on January 22, 2002, assisting the environmental cleanup being performed by Earthmovers, Inc. The emergency operations center remained

[11] *Hot zone* refers to an area in which a hazardous material release has occurred. It can also refer to an area immediately surrounding a hazardous materials incident that extends far enough to prevent adverse effects from hazardous materials releases to personnel outside the zone.

open on a limited basis until March 19, 2002. Some residents of Tierracita Vallejo were not able to return to their homes until the second week of March 2002.

Trinity Hospital

Trinity Hospital activated its disaster plan, "Code Green," at 2:25 a.m., 35 minutes after the emergency room was notified of the derailment at 1:50 a.m. Approximately 200 medical personnel came to the hospital in response to the Code Green. The additional personnel supplemented the 41 staff members already at the hospital. Staff secured the hospital against the hazardous vapors by shutting down air handlers, setting up a portable air-handling unit in the emergency room, and establishing an alternate emergency room entrance away from the vapor cloud. The emergency room staff told Safety Board investigators that they consulted a material safety data sheet to find out how to effectively treat persons exposed to ammonia. Additionally, Trinity Hospital sent a representative to the emergency operations center. By 4:15 a.m., the ammonia cloud had drifted to and encompassed the hospital. Throughout the emergency, Trinity Hospital treated approximately 300 people.

Ward County 911

Throughout the day of the accident, Ward County 911 dispatchers answered more than 2,800 calls concerning this accident—491 calls on four enhanced 911 lines[12] and an additional 2,362 calls on seven administrative lines. When the first 911 calls came in, the Ward County 911 operators told callers to stay in their homes and close their windows. Throughout the course of the emergency response, the operators continually told callers to remain calm and remain in their homes. The 911 dispatchers were made aware of the chemical involved immediately, and they passed the information along to callers. The 911 operators told callers to:

> … stay in their homes and shut down their furnaces and air handling systems, go into their bathroom and use large amounts of water—turn on their shower and breathe through a wet cloth.

Public Notifications

After the accident, the Minot Police Department made emergency notifications to the public that included cable television interrupts, radio broadcasts, and outdoor warning sirens. However, many residents did not hear the emergency broadcasts because their homes had lost power as a result of the derailment. Additionally, residents of the houses in the neighborhood closest to the derailment did not hear the outdoor warning sirens because the sirens are positioned to be heard within the city limits of Minot.

The Minot Police Department attempted to contact the designated local emergency broadcast radio and television stations. At the time of the accident, only one person was working at the designated local emergency broadcast radio station (KCJB-AM), and the police department's calls to the station went unanswered. The designated local emergency

[12] Enhanced lines have a display that allows the 911 operator to see the address of the caller.

broadcast television station (KMOT) did not have an overnight crew at the station. To arrange emergency broadcasts, the police department had to contact the KMOT news director at his home.

Injuries

Train Operating Crew

The conductor and engineer of CPR train 292-16 sustained minor injuries as a result of this accident. They were both taken to Trinity Hospital after the derailment. The conductor was admitted approximately 3 hours after the accident and treated for chest tightness, shortness of breath, eye irritation, and anxiety. He was discharged on January 19, 2002. The engineer was treated for difficulty breathing and released the same day.

Emergency Responders

Of the 122 firefighters who responded to the accident, 7 sustained minor injuries. The injuries to six Minot Rural Fire Department firefighters and one Burlington Fire Department deputy chief were headaches, sore throats, eye irritation, and/or chest pain.

An additional 11 Minot Police Department officers sustained minor injuries while blocking and directing traffic around the perimeter of the accident scene. Their injuries were eye irritation, chest discomfort, respiratory distress, and/or headaches.

One Ward County Sheriff's Department lieutenant sustained minor injuries as a result of the accident. The lieutenant had stationed his vehicle south of 4th Avenue on the West Bypass to prevent traffic from entering the area. Soon afterwards, a chemical cloud engulfed his vehicle, and he became disoriented. While attempting to exit the area, he drove his car into a ditch and remained inside his vehicle for approximately 45 minutes until rescuers arrived. He was then taken to Trinity Hospital and released after being treated for toxic effects of anhydrous ammonia.

Residents

The driver of the truck that crashed into a house in the Tierracita Vallejo neighborhood while attempting to flee the area, a 38-year-old male, sustained fatal injuries. The Ward County coroner determined that the cause of death was prolonged exposure to anhydrous ammonia.

Three residents of the Tierracita Vallejo neighborhood sustained serious injuries as a result of the accident and were admitted to Trinity Hospital. Their injuries included chemical burns to the face and the feet, respiratory failure, and erythema[13] of the eyes and the nose.

[13] Abnormal redness caused by capillary constriction.

Eight other residents of Minot sustained serious injuries as a result of the movement of the ammonia cloud over parts of the city of Minot. The injuries, which included shortness of breath, difficulty breathing, and/or burning of the eyes, were determined to be have been complicated by pre-existing health problems such as asthma and heart conditions.

A total of 301 other persons sustained minor injuries as a result of the accident. Of these, 11 were admitted to Trinity Hospital for less than 48 hours. The remaining 290 individuals were treated and released at either Trinity Hospital, the triage center established at Edison Elementary School in Minot, the Minot Air Base Health Clinic, Kenmare Community Hospital, and/or St. Alexius Medical Center. (See table 1.)

Table 1. Injuries.

Injury Type[a]	Train Operating Crew	Emergency Responders	Residents	Total
Fatal	0	0	1	1
Serious	0	0	11	11
Minor	2	19	301	322
Total	2	19	313	334

[a] 49 *Code of Federal Regulations* (CFR) 830.2 defines *fatal injury* as "any injury which results in death within 30 days of the accident" and *serious injury* as "an injury which: (1) requires hospitalization for more than 48 hours, commencing within 7 days from the date the injury was received; (2) results in a fracture of any bone (except simple fractures of fingers, toes, or nose); (3) causes severe hemorrhages, nerve, or tendon damage; (4) involves any internal organ; or (5) involves second- or third-degree burns, or any burn affecting more than 5 percent of the body surface.

Damage

Equipment

The first 30 derailed cars were completely destroyed in the accident. The 31st car sustained damage to one corner of the car and the under frame. The CPR estimated the replacement value of the derailed equipment to be $1,966,000. Monetary loss from the damaged or destroyed lading was estimated to be $340,000. Total estimated damages were $2,486,000.

Track

As a result of the derailment about 475 feet of the main track were destroyed, accounting for approximately $180,000 in track damage. Thirteen track panels[14] were installed to restore operations.

[14] Panels are pre-made 39-foot sections of track with rail and ties attached. They are transported to a derailment site by truck, laid, and connected, and they provide a temporary method of moving trains after track has been destroyed.

Environmental Remediation

As of January 2004, the CPR has completed the following environmental remediation activities, at a cost in excess of $8.39 million, in response to the toxic anhydrous ammonia release:

- Conducted approximately 135 soil borings to guide general soil excavation.
- Installed 28 monitoring wells.
- Removed approximately 98,700 tons of soil exhibiting ammonia concentrations greater than 500 mg/kg from the general site and trackbed area.
- Removed approximately 25,000 square feet of ice from the Souris River.
- Installed groundwater collection sumps in topographic low areas located south and north of the mainline track.
- Installed and continued operation of a groundwater extraction system.
- Developed a site-wide groundwater monitoring program.
- Completed a track bed soil/groundwater assessment and excavation program.
- Completed a tank car staging area assessment and excavation program.
- Collected approximately 1,145 surface water samples from the Souris River and 212 ground water samples.
- Conducted, in December 2003, an additional track bed assessment that included completing 23 push-probe borings to collect an additional 87 soil samples.

Other Damage

As a result of the derailment, two houses in the Tierracita Vallejo neighborhood were damaged. One section of tank car GATX 47982 (car 22) was propelled approximately 1/4 mile east of the derailment, crashing into a room in which two people were sleeping. (See figure 6.) The second house damaged was the one struck by the truck in which two residents were attempting to leave the area. (See figure 7.)

Figure 6. One section of tank car GATX 47982 (car 22), indicated by the arrow, was propelled approximately 1/4 mile east of the derailment, crashing into a room in which two people were sleeping.

Figure 7. House struck by truck in which two residents attempted to leave the area.

Personnel Information

The engineer and the conductor had been off duty for 13 hours and 46 minutes before this trip. Both men met the provisions of the Federal Hours of Service Act. After the accident, both crewmembers of the train crew underwent mandatory Federal Railroad Administration (FRA) postaccident drug and alcohol testing at Trinity Hospital. Test results were negative for all tested substances for both employees.

Engineer

The engineer began his railroad career with the track department in 1993. He transferred to the operating department later that year and worked as a switchman. He was promoted to engineer in 1996 and held that position until the accident. The engineer had taken and passed rules exams in 1993, 1994, 1995, 1996, 1998, and 2000. He had been certified as a locomotive engineer since 1996, and most recently had completed an engineer recertification class on March 2, 2001.

Conductor

The conductor started with the railroad in 1996 and worked in train service until the accident. He had passed rules exams in 1996, 1998, and 2000.

Track Maintenance Supervisor

The track maintenance supervisor ordered material and set up schedules for the tampers and welders and was tasked with making sure that the employees who worked for him did the right track inspections. He was designated by the CPR as qualified under 49 *Code of Federal Regulations* (CFR) 213.7, “Designation of qualified persons to supervise certain renewals and inspect track.” He worked for the service area manager of engineering and was responsible for more than 288 route miles of track and 21 engineering employees. He started with the Soo Line Railroad as a section laborer in 1977. He was promoted to assistant foreman, to foreman, and to track maintenance supervisor (formerly called roadmaster).

Section Foreman

The section foreman’s normal duties were to repair track defects and to perform supplementary track inspections. He was designated by the CPR as qualified under 49 CFR 213.7. Three employees worked for him, and he worked for the track maintenance supervisor. He started working for the Soo Line Railroad as a laborer in 1973.

Track Inspector

The track inspector’s normal duties were to inspect the track and repair track defects. During an interview he said, “… I go out and find anything that is unsafe as far as the railroad’s rail is concerned, any rail situations, track situations, anything that would prevent a train from safely going over the rail.” He was designated by the CPR as qualified under 49 CFR 213.7. He started working for the Soo Line Railroad in 1952 and had worked as a track inspector since 1967.

Meteorological Information

On January 18, 2002, at Minot, ND, the maximum temperature was 20° F, and the minimum temperature was -8° F. It was approximately -6° F at the time of the derailment. Peak winds that day were 26 mph at 1:39 p.m.; in the early morning hours the winds were reported to be from the southwest at 6 to 7 mph. Cloudy skies prevailed most of the day. Light snow fell between 3:18 p.m. and 4:54 p.m. Mist, fog, or haze, which reduced visibility to less than 7 miles, was reported at times from 2:54 a.m. to 12:54 p.m. Only a trace of precipitation was reported (less than 0.01 inch) during the day. Sunrise was at 8:28 a.m. and sunset at 5:23 p.m.

Operations Information

Train movements on the CPR Portal Subdivision (Portal to Harvey) were authorized and governed by track warrants[15] issued by the Portal train dispatcher in Minneapolis, Minnesota. The accident crew was in possession of a track warrant that authorized them to proceed at track speed (in this case, 40 mph) because no other trains would be encountered on the single main track. The Portal Subdivision did not have wayside signals or electrical circuits in the rail to check for train occupancy or track integrity.

The crew's standard operating procedures were contained in the General Code of Operating Rules, Fourth Edition, April 2, 2000. Specific modifications were in Timetable No. 3, effective Sunday, April 2, 2000.

Site Description and Track Information

Track Description

The derailment occurred on the CPR's Portal Subdivision of the St. Paul Service Area on the single main track at MP 471.65, which is west of the city of Minot, North Dakota, within the limits of Ward County. The main track is owned, inspected, maintained, and operated by the CPR. The majority of the Portal Subdivision's 152.5 miles of main track was classified as class 4 track that had a maximum allowable operating speed of 49 mph for freight trains.[16] Portions of the subdivision, including the derailment site, were maintained as FRA class 3 track with a maximum speed of 40 mph.

[15] A *track warrant* is a written instruction issued by the train dispatcher directing a crew to operate a train from one specific location to another.

[16] Railroads determine how they will classify various segments of their track. As the class designation increases, the track must meet increasingly higher Federal standards for construction, maintenance, and inspections. Federal regulations also establish maximum speeds for each class of track. The maximum speed for freight trains on class 4 track is 60 mph in signaled territory and 49 mph in non-signaled territory (such as the Portal Subdivision).

The Portal Subdivision had a daily train density between 3 and 5 trains in each direction, or 6 to 10 trains each day. This accounted for an annual gross tonnage in 2001 of about 25 million gross tons. The gross tonnage had been increasing from an estimated 15 million gross tons 10 years earlier.

The track where the train derailed was tangent (straight) and flat. The CPR right-of-way was 100 feet wide. The main track structure at the point of derailment was built on about 6 feet of fill, as measured from the ditch line to the top of the subgrade. The track segment was supported with basalt ballast 6 to 8 inches deep under the crossties. Within the area adjacent to the derailment site the ballast was about 12 inches deep at each shoulder width, and the cribs[17] were full of ballast.

Track Joints

The main track in the tangent areas was laid with 100-pound[18] continuous welded rail (CWR), and the curves were 115-pound CWR. The rail was used CWR re-laid on the Portal Subdivision in 1973. Records did not identify the previous location of the rail. Even though the rail throughout the subdivision was CWR, it had numerous joints where defective sections of rail had been cut out and replaced with pieces of matching[19] rail called "plugs." Each end of the plug was spliced into the CWR with two 36-inch joint bars, which fit against the inside and the outside of the rail and are fastened with bolts through both bars, sandwiching the rail between the bars. (See figure 8.) Such repairs in CWR are common in the railroad industry. Railroads often later remove the joint bars and weld the joints.

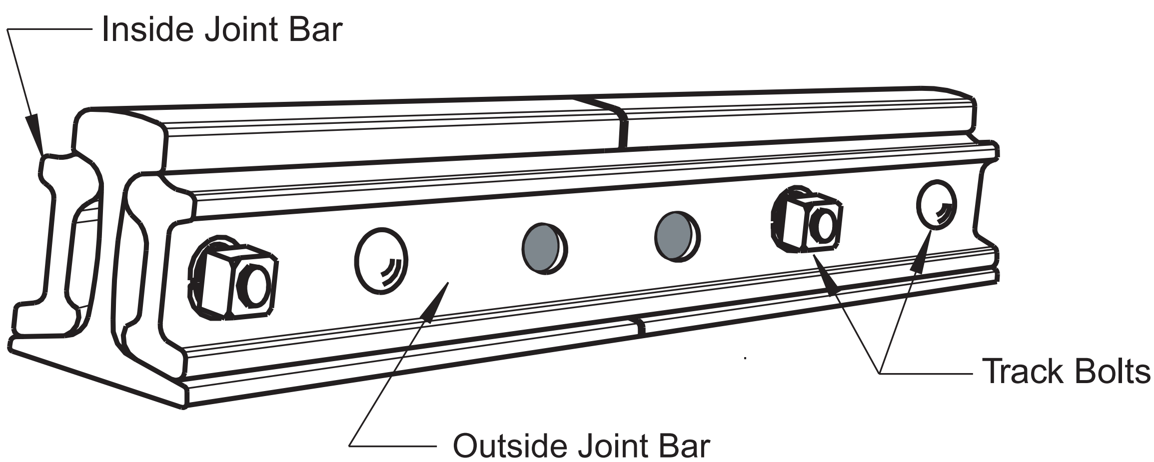

Figure 8. Sketch of a typical joint bar.

[17] A *crib* is the space between the crossties.

[18] Rail is measured in weight per linear yard. This rail was labeled 10025 RE and 11525 RE, indicating that the rail was 100 pounds per yard and 115 pounds per yard, respectively, and manufactured to American Railway Engineering Association specifications. The 25 was a manufacturer's designation.

[19] The rail was matched by weight (100.25) and comparable wear so that the top of the rail would be approximately level.

A CPR capital improvement project in 1998 involved, among other tasks, removing about 2,600 joint bars from about 1,300 joints in the Portal Subdivision and welding the rail joints. Since 1998, additional plugs have been used to replace defective rail. In May 2000, a 36-foot plug was inserted with 36-inch joint bars in the north rail in the area of the 2002 derailment, MP 471.65, after ultrasonic rail testing discovered an internal defect in a section of the existing CWR. Based on postaccident rail reconstruction, inspection of the undisturbed track, a visual survey of the derailment "footprint," and a review of previous ultrasonic rail test records, investigators eventually determined that the derailment occurred at or near the plug that been inserted into the north rail in May 2000.

In testimony during a public hearing on July 15 and 16, 2002, in Washington, D.C., the CPR section foreman said that he followed the CPR's standard practices[20] in May 2000 when he inserted the plug and created the two joints at the accident site. Rail joints can be either supported (placed on a tie) or suspended (placed over the ballast crib, between ties). In this case, the foreman suspended the joints over the ballast cribs. It is common industry practice to suspend the rail ends over the crib if the joint is expected to be welded in the future because such placement provides 360-degree access for welding.

Each joint bar is pre-drilled with six bolt holes. Matching holes are then drilled through the web of the rail to allow attachment of the bars. If a joint is expected to be welded later, the railroad will often drill only the outermost four holes (the farthest two from the rail ends). The joints for the plug at MP 471.65 had only four bolts. In CPR's vernacular, this joint was a temporary joint, rather than a permanent joint, which would have had all six holes drilled and would have been assembled with six bolts.

The east joint of the plug inserted in May 2000 at the derailment site was suspended over a ballast crib span that was wider than in nearby areas—about 25 inches, as measured between the edge of the tie plates on each side of the joint. FRA regulations state that the point where the rails meet must be no more than 24 inches from the centerline of the nearest nondefective tie. This rail joint was approximately 13 inches from the east tie center and approximately 19 inches from the west tie center.

Rail Movement

Steel rail expands in hot weather and contracts in cold weather. When jointed track is laid in 39-foot sections, the joints are generally designed to allow for expansion. However, in CWR, because of its long runs of un-jointed rail, the effects of temperature changes—expanding in the heat and shrinking in the cold—can accumulate over great distances. When these forces reach a weak point in the track structure, an irregularity may occur. The Safety Board has investigated accidents in which track had buckled from heat expansion or pulled apart because of rail shrinkage in cold temperatures.

Bent bolts and rail end gaps at joint bars are indications that rail has moved longitudinally, or pulled apart. The CPR track maintenance foreman, during the Minot accident public hearing, recalled replacing the bolts in one of the joints of the plug at the

[20] *Standard practices* for the foreman referred to how he normally performed the work. How he determined the standard practices is explained later in this report.

accident site in the summer of 2001. He said that the bolts needed replacing because they were bent. He further remarked that he replaced the bolts because it “saves a lot of problems during winter.”

To prevent longitudinal rail movement, rail anchors are applied to CWR. To restrict movement in either direction, the customary practice is to use a box anchor pattern in which anchors are placed on the base of the rails on both sides of the wooden crosstie, essentially boxing the wooden tie with rail anchors. The box pattern can be applied to every tie or every other tie for a specified distance from the joint in each direction. At the Minot accident site, the anchors were applied to every other tie.

The practice of box anchoring was described by an FRA railroad track specialist as follows:

> Box anchoring every tie in the vicinity of bolted joints reduces the tendency of the rail ends to separate and shear the joint bolts during cold temperatures. Normal industry standards call for both rails to be fully box-anchored on every tie for 200 feet in both directions from a bolted joint in either rail. This full box-anchoring pattern occurs at other locations where axial forces can be problematic such as special work (that is, turnouts and switches), sharp curves, etc. Elsewhere, every other crosstie is box-anchored.

A method of determining whether rail has moved is by examining the contact point between the rail and the tie plate. (See figure 9.) The underside of the rail is shiny at this point because of the abrasive action that occurs where the rail rests on the tie plate. If the track has moved longitudinally, the shiny area is wider than the width of the tie plate. The shiny areas were measured on the rail that fractured at the east joint of the plug, and the tie plates that contacted the rail were also measured. The shiny areas on the rail were 8 inches wide, and the tie plates were 7 3/4 inches wide.

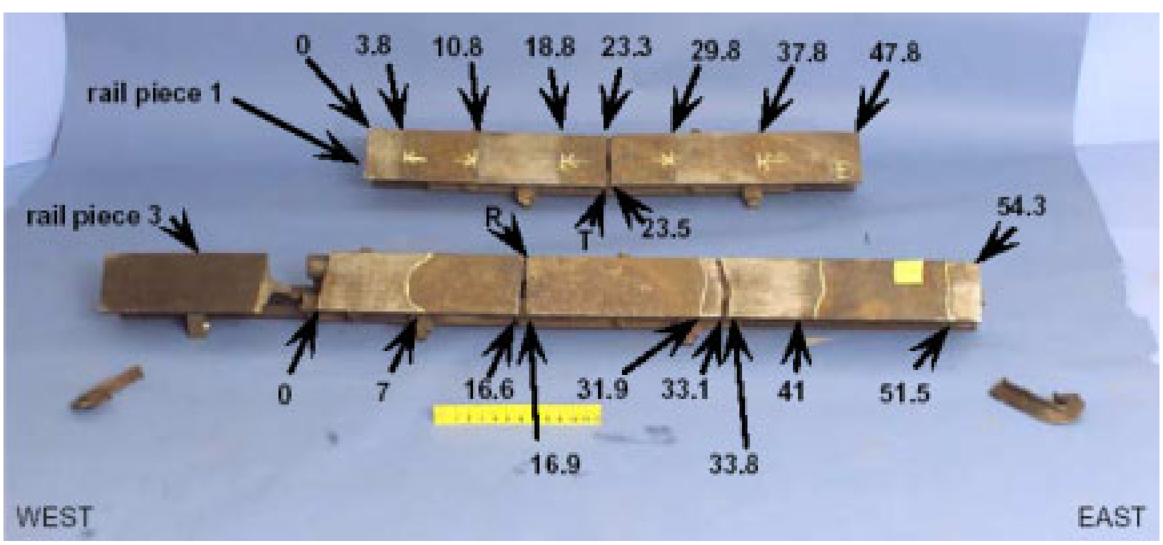

Figure 9. Underside of the recovered pieces of rail from the north side of the track. Pieces placed as they were before they were fractured. The numbers indicate the distance in inches from the “0” arrows.

Track Inspections

The CPR's track inspection records from the 90 days preceding the accident did not identify any track deficiencies in the area of the derailment. The FRA minimum requirements for track inspections for this class of track (class 3 or 4) was twice weekly with at least 1 calendar day between inspections. These inspections could be done by walking or by using a Hy-Rail vehicle.[21] Records indicated that during cold weather, the CPR inspected the track four to five times a week using a Hy-Rail vehicle. The derailment area was inspected on January 17, 2002, the day before the accident.

According to the testimony from maintenance-of-way employees, an inspection of joints from the ground (as opposed to using a Hy-Rail vehicle) was specified by the CPR in the spring of each year or any time a joint appeared to need a close inspection. The railroad did not collect or retain data on the results of those inspections, and railroad officials were unable to determine when the last on-the-ground visual inspection of the track and joint bars in the accident area had been performed. Between on-the-ground inspections, it was customary for a track inspector to visually inspect the joints from within the moving Hy-Rail. The employees stated that while operating the Hy-Rail over a joint, the inspector would listen for sounds that would indicate that the joint was loose or otherwise defective.

Title 49 CFR 213.121 contains regulations regarding joint bars. The section states that joint bars will be structurally sound and of the proper dimensions for the rail. It also specifies the minimum bolting pattern for various classes of track. Although the section directs that cracked or broken joint bars be replaced, it offers no guidance on how or how often joint bars should be inspected for cracks or conditions that can lead to cracks or fractures.

On October 1, 2001, an FRA track inspector inspected the CPR's Minot Yard and main track in Minot east of the derailment site. The following joint bar deficiencies were noted:

- One "center cracked or broken" joint bar deficiency in a compromise bar on 10 mph track (class 1) on the north rail at the Voltairi Siding.
- Two joint bar deficiencies noted as "rail joint not structurally sound design and dimension," which referred to a pair of bars that had been improperly assembled on a 10 mph track.

On October 2, 2001, the FRA track inspector covered 40 miles of the CPR's main track, from Balfour, North Dakota, (in McHenry County, east of Minot) into the city of Minot. According to his report, he inspected 13 main track turnouts, 16 derails,[22] and 11 yard turnouts. He walked one section of main track and two sections of yard track, and he made two roadway worker observations. The report was acknowledged by the CPR's track

[21] A Hy-Rail vehicle is a maintenance-of-way highway vehicle, in this case a pickup truck, that is equipped with flanged wheels that can be lowered to allow the vehicle to travel on railroad tracks.

[22] A *derail* is a moveable device placed short of the clearing point on a main track to derail a car or engine that would otherwise foul the main track.

maintenance supervisor. During that inspection, he noted a total of 25 items representing 32 deficiencies, as follows:

- Eighteen main track turnout deficiencies: four “heel of switch insecure;” six “loose adjustable rail braces;” two “loose, worn, defective connecting rod fastening;” five “loose, worn, missing frog bolts;” and one “guard check gage less than allowable.”
- Ten main track deficiencies observed while Hy-Railing: seven “combustible vegetation around track-carrying structures—bridges;” two “vegetation obstructs visibility of railroad signs and fixed signals;” and one “drainage or water-carrying facility obstructed by vegetation.”
- One yard turnout deficiency: “one loose, worn, defective connecting rod fastening.”
- Three yard track deficiencies: one “center cracked joint bar;” and two “rail joint bars not structurally sound design and dimension.”

On October 3, 2001, the FRA inspector observed 38 deficiencies on a variety of FRA classes of track. Twenty-four of the 38 deficiencies were in class 1 track, various 10-mph yard track, and wye tracks. The yard track deficiencies included a citation for “center cracked joint bar.” Thirty of the 38 deficiencies were written for turnout noncompliance: 14 for main track turnouts, and 16 for yard turnouts. The balance of the deficiencies (8) in the yard were written for two items of gage, one for crosslevel, one for defective crossties, a bolting condition, and three for “joint bar not structurally sound in design or dimension.”

On October 4, 2001, the inspector checked 30 miles of main track beginning with the first road crossing west of the derailment area and moving west. His report noted that he inspected nine main track turnouts and three yard turnouts, he walked one section of main track and one unit of yard track, and he made two roadway worker observations. The report was acknowledged by the CPR’s track maintenance supervisor. During that inspection, the FRA inspector noted a total of seven items representing seven deficiencies, as follows:

- Five main track turnout deficiencies: three “loose adjustable rail braces;” one “loose or missing frog bolt;” and one “bolting deficiency for less than two bolts per rail at each joint for conventional jointed rail in classes 2 through 5 track.”
- Two main track deficiencies: one “vegetation obstructs visibility of railroad signs and fixed signals;” and one “bolting deficiency for less than two bolts per rail at each joint for conventional jointed rail in classes 2 through 5 track.”

None of the deficiencies noted over the 4 days of inspections was identified as a violation; thus, the CPR was not required to report to the FRA any remedial actions taken.[23]

[23] A deficiency that is not noted on the FRA inspector’s report as a potential violation remains classified as a deficiency. In this case, the FRA inspector does not have the option of requiring FRA notification of remedial actions.

The FRA inspections were conducted at times and locations where train movements would not be affected; as a result, the four October 2001 FRA inspections did not cover the derailment area. The most recent FRA inspection of the accident area had been completed 13 months before the accident, on December 6, 2000. No defects were noted in the derailment area during that inspection.

Ultrasonic Rail and Joint Bar Testing

The most recent internal rail inspections using ultrasonic devices on the Portal Subdivision's main track were conducted on May 31 and August 29, 2001, and January 10, 2002. Sperry Corporation, which conducted the tests, found no defective rails in the derailment area. The Sperry testing was capable of finding defects (above a certain size) in the rail but not in the joint bars.

The Safety Board investigated a derailment that occurred February 27, 1994, near MP 477.1, less than 6 miles west of the Minot accident on the same CPR territory. The Safety Board determined that the probable cause of the accident was "a joint bar or bars [that] broke under the dynamic forces of the moving train, and failure of the railroad to properly maintain the track structure."[24] Records indicate that, following the accident, the CPR ultrasonically inspected joint bars with a handheld device. This device could scan for internal defects and visually undetectable cracks. As joint bars were removed and track joints were welded as part of the 1998 capital improvement program, the number of inspections by handheld ultrasonic devices decreased until the inspections finally ceased altogether. Between the capital improvement program in 1998 and the time of the accident, about 47 plugs, or 94 rail joints, were added to the territory.

Track Geometry Measurements

During 2001, the CPR operated its track geometry car[25] three times on the Portal Subdivision main track. The most recent of these on this segment of the Portal Subdivision main track was on August 29, 2001, using CPR test car No. 64. No geometry defects were noted within the area of the derailment.

Postaccident Inspection

Equipment

Maintenance, inspection, and repair records for the locomotives and all cars in the train were reviewed, and nothing unusual was found. Additionally, the locomotives and all cars on the train were mechanically inspected and evaluated after the accident. The results of those inspections are detailed below.

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[24] NTSB, CHI-94-FR-009, Burlington, North Dakota, 02/27/94, File No. 597.

[25] This car takes dynamic measurements of the track geometry, which among other things includes degree of curves, gage, and rail elevation.

Locomotives. CPR locomotive units 9106 and 8631 were inspected and tested. Air pressure was not lost during the main reservoir leakage test, and air brake piston travel was within limits on each brake cylinder. All periodic inspections were within their limits on both locomotives. The headlight, ditch lights,[26] horn, bell, radio, and sanders[27] all functioned as designed.

The wheels of both locomotives were inspected. On the lead locomotive, CPR 9106, the third wheel from the front on the left side had an approximately 1/2-inch-wide by 1/4-inch-high abrasion near the center of the tread. There was metal flow out of the abraded area. The wheels on the left side were on the north rail when the train operated through the accident site.

Cars. All of the cars from the train were inspected. Of the first three (non-derailed) cars behind the locomotives (the first car to derail was the fourth car), the inspection revealed that all 12 wheels[28] that had been on the north rail displayed vertical abrasions across their treads. The wheels that had been on the south rail had no corresponding abrasions. The abrasion marks were more pronounced on the cars farthest from the locomotives. In addition, the location of the marks varied from the inside of the tread on some of the wheels to the outside of the tread on other wheels.

Among the non-derailed cars, four mechanical defects were noted: GATX 61011 was missing 50 percent of a 2-inch composition brake shoe on the front right wheel; CSXT 502692 was missing a sill step bolt on the left side of the A[29] end; AOUX 50006 was missing 50 percent of a 2-inch composition brake shoe on the second wheel on the left; and EOGX 4137 had a brake rod worn to less than one-half of its original thickness. An air brake test of the non-derailed cars resulted in an acceptable combined leakage of 1 pound per square inch (psi) per minute.

The wheels on all the derailed cars were also inspected. No flat spots or built-up tread was observed on any wheel. Three broken wheels and one loose wheel were observed. All the broken wheels displayed new fracture surfaces without any evidence of batter.[30] The wheel seat for the loose wheel did not exhibit any rotational scouring.

Track

The accident site was inspected visually after the derailment. Investigators found no marks on the rail immediately before the point of derailment. The inner guard rails on

[26] *Ditch lights* are supplemental lights that shine forward and along the ditches on the sides of the railroad.

[27] A *sander*, consisting of a hopper and piping directed in front of the wheels of the locomotive, delivers sand to the top of the rail to improve traction.

[28] The three head cars had 4 axles each; therefore there was a total of 12 axles. Each axle has 2 wheels; thus 12 wheels were on the north rail and 12 wheels were on the south rail.

[29] The end of a freight car that has the hand brake is called "B," and the opposite end is called "A."

[30] *Batter* is deformation caused by impact. The term is used for rail deformation and also for impact marks found on the treads of the steel wheels.

the bridge at MP 471.95 showed no indications of contact by a wheel or by dragging equipment. The first FRA walking track inspection after the derailment noted no exceptions in the undisturbed sections of track immediately adjacent to the derailment area. On January 28, 2002, after the track repairs were completed and traffic resumed, the FRA inspected the main track from Minot to Portal. During those inspections, seven cracked joint bars were found that had not been discovered by CPR maintenance-of-way workers during their immediate postaccident inspections. When these bars were subjected to an unscientific "drop test," it was found that bars with as little as a visible 1/8-inch crack fractured upon being dropped over a railhead from a height of about 5 feet. The fracture faces in those bars were similar in size and shape to the joint bar fractures discovered in the derailment area. From January 25 to February 8, 2002, three FRA track inspectors inspected CPR main track from Portal, Minnesota, to the border between North Dakota and Minnesota. It was during those inspections that the FRA issued the CPR violation and "Notice of Special Repairs" reports.

On January 24, 2002, a geometry car tested the main track from Portal to Harvey, North Dakota. No urgent defects[31] or exceptions of track geometry were found during the test. Track geometry includes gage,[32] crosslevel,[33] and alignment. All the measurements were within the allowable threshold for FRA class 3 and 4 track, where applicable.

Rail and Joint Bars

Pieces of rail and joint bars from the accident site were recovered, reassembled, and initially examined before portions were shipped to the Safety Board's Materials Laboratory. Pieces of the south rail contained fractures indicative of overstress separation with no evidence of pre-existing fractures. The east end of the 36-foot plug from the north rail was found to be fractured into several pieces. The joint bars from the east end of the plug had fractured vertically at the mid span. The face of the joint bar fracture had signs of discoloration. The joint bars at the west end of the plug were intact.

Laboratory Tests and Examinations

The pieces of the plug and the joint bars from the north rail and CWR associated with the joints were shipped to the Safety Board's Materials Laboratory for examination.

The recovered pieces of rail and joint components from the north rail are shown in figure 10. The rail pieces are labeled 1 through 6 (west to east). The bolts and bolt holes for the west joint bars are labeled A through D, and the bolts and bolt holes for the east joint bars are labeled E through H. Rail piece 1 was from the CWR on the west side of the

[31] *Urgent* defects exceed FRA minimum standards for a certain class of track.

[32] *Gage* is the distance between gage lines of rails laid in track. A *gage line* is a line 5/8 inch below the running surface of a rail on the side of the head nearest the track center, and is the line from which measurements of gage are made.

[33] *Crosslevel* is the distance one rail is above or below another.

plug. Rail pieces 2, 3, and 4 were from the 36-foot plug installed in May 2000. Rail piece 4 was the easternmost piece of the plug, and the fracture on the west end of this piece matched the fracture on the east end of piece 3. Rail pieces 5 and 6 were from the CWR on the east side of the plug, and a portion of the fracture on the east end of piece 5 matched a portion of the fracture on the west end of piece 6. As shown in figure 10, the joint bars at the east end of the plug were fractured between pieces 4 and 5. The joint bars at the west end of the plug (between pieces 1 and 2) were intact.

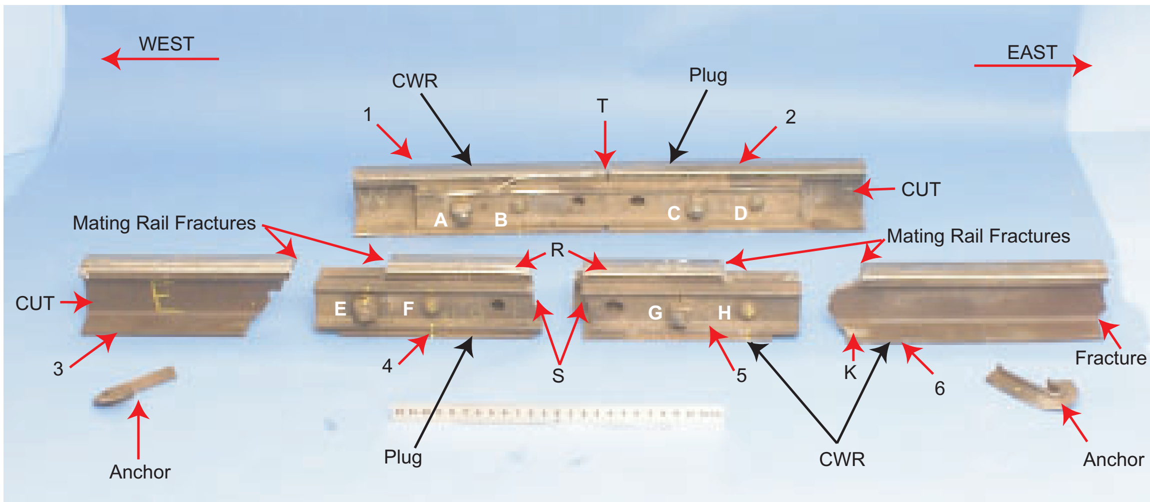

Figure 10. Recovered pieces of rail and joint bars from the north side of the track. Arrows “S” indicate the location of the fracture on the pair of joint bars from the east end of the rail plug. Arrows “R” indicate the joint between rail pieces 4 and 5. Arrow “T” indicates the joint between rail pieces 1 and 2.

Rail piece 4, the easternmost piece of plug rail, exhibited a mark on the top of the rail, an impact mark on the fractured end of the joint bar, and an impact mark on a track bolt identified as bolt G on the gage side.

East Joint Bar Fractures

Figure 11 depicts the fracture faces of the joint bars. The joint bar on the gage side contained a 2.1-inch fatigue crack that originated from the top of the bar in the area marked “01,” extended downward through a portion of the web, and terminated in the area indicated by the dashed line. This fatigue crack was externally visible (not obstructed by the rail) over a length of 1.9 inches. The same joint bar contained another fatigue crack that emanated from the bottom of the bar in the area marked “02.” This fatigue crack propagated into the web portion and terminated at the web area indicted by a dashed line. The length of this fatigue crack was approximately 1.9 inches. This fatigue crack was externally visible (not obstructed by the rail) over a length of about 2 inches (when measured along the exterior surface contour). The area between the two fatigue regions showed features of overstress separation. The field side joint bar had a fatigue crack that emanated from the top of the bar in the area marked “03.” This fatigue crack propagated approximately 0.9 inch into the web portion to the area indicated by a dashed line. This fatigue crack was externally visible (not obstructed by the rail) over a length of 0.8 inch. The remaining portion of the joint bar showed features of overstress separation. Visual examination did not reveal any other cracks in the east joint bars.

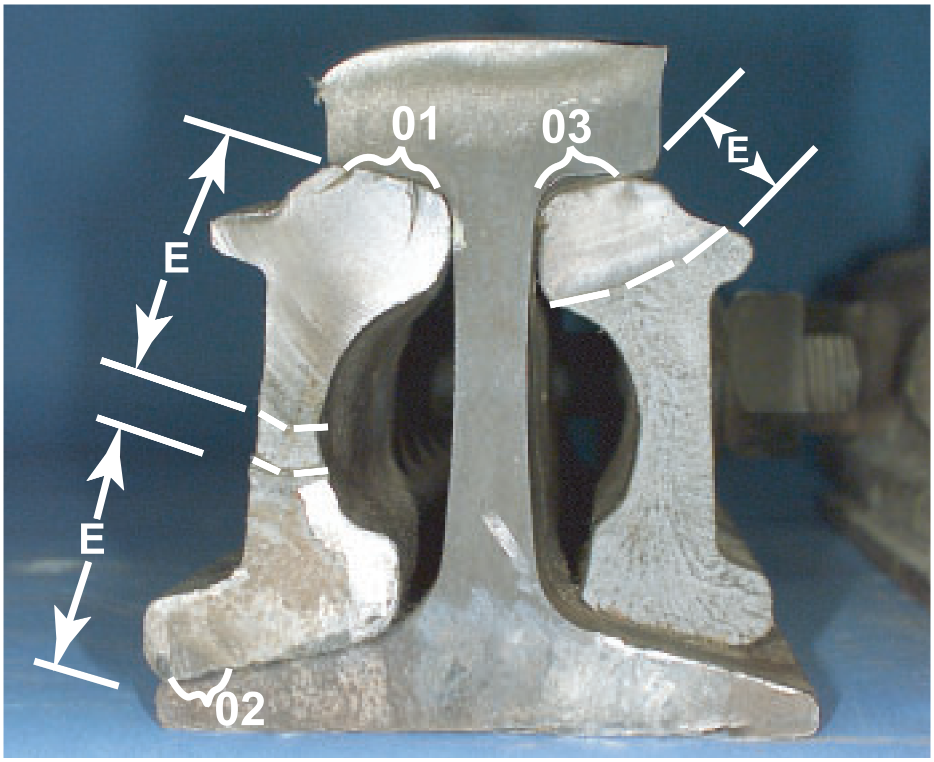

Figure 11. West faces of the fractured joint bars showing fatigue origins 01, 02, and 03. The gage side is on the left. Area between arrows “E” indicates portion of a fatigue crack that was exposed to the exterior surface.

As shown in figure 10, the joint bars from the west joint of the plug were bent but not broken, and were received in the laboratory still attached to pieces of rail. Visual, ultrasonic inspection, and dye penetrant inspection of these bars did not reveal any cracks.

Rail Fractures and Cracks

The fracture between plug rail pieces 3 and 4 contained a 0.4-inch fatigue crack that emanated from rail bolt hole E (west side of the bar, the farthest from the joint). The remainder of this fracture was typical of overstress stemming from the fatigue crack. Piece 4 contained a crack between the head and bolt hole F. The crack was exposed by making a saw cut from the bottom of the rail up to this bolt hole. The exposed fracture face showed a 0.3-inch fatigue crack that originated at bolt hole F. The remainder of this crack was typical of overstress stemming from the fatigue crack. Piece 5 contained a crack that extended from bolt hole G, which was not sawed open in the laboratory. The fracture face on the east side of piece 5 contained a 0.3-inch fatigue crack that came from bolt hole H. The remainder of this fracture was typical of overstress that stemmed from the fatigue crack.

Testing of the Fractured Joint Bars

Requirements for chemical composition and tensile and bend testing of joint bars are specified by the American Railway Engineering Association (AREA) and the American Railway Engineering and Maintenance-of-Way Association (AREMA).[34] Specimens for tensile and bend[35] testing were manufactured from the head portion of the fractured joint bars and chips of material from the machining operation were subjected to chemical analysis. Results of the chemical analysis, tensile, and bend tests met the requirements in the AREA and AREMA specifications.

Conditions Found at the Joints

Rail Gap At Joints. The butt ends of the rails at the east plug rail joint on the north rail were examined and found not to be cut squarely so that if the bases of the rails made contact, the tops of the rails would not. Calculations based on laboratory measurements indicated that, at minimum, the gap at the top of the rail was 0.359 inch. Furthermore, taking into account wear and deformation in the bolts, the gap was calculated to be between 0.459 inch and 0.659 inch when under tension stresses.

The gap between the rails at a joint has a negative effect on the fatigue life[36] of the joint. According to the reports by Dr. Jeong from the Department of Transportation's Volpe National Transportation Systems Center,[37] "The results indicate that as the gap distance increases the dynamic load at the joint increases (because the wheel has a greater distance to drop) which in turn decreases fatigue life." The report concludes that the actual calculations are just the groundwork, and "moreover, the calculations presented here for joint bars are theoretical in nature and have not been validated through testing."

The rail in the accident area was placed on wooden crossties with an average of 24 crossties for every 39 feet. The rail was supported with double-shoulder tie plates[38] that measured 7.75 inches wide by 10.5 inches long. Standard 6-inch cut spikes fastened the rail and tie plates to the crossties. The spiking pattern varied between two and three 6-inch cut track spikes per tie plate. When three spikes were used, the general spiking pattern was one field-side[39] rail holding spike, one gage-side[40] rail holding spike, and one gage-side tie

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[34] AREMA was formed on October 1, 1997, as the result of a merger of three engineering support associations: the American Railway Bridge and Building Association, the AREA, and the Roadmasters and Maintenance-of-Way Association, along with functions of the Communications and Signal Division of the Association of American Railroads.

[35] Bend specimens (7 inches by 0.5 inch by 0.5 inch) were bent 90° cold around a 1.5-inch-diameter rod. The surface of the specimens showed no evidence of cracking after the bend test.

[36] *Fatigue life* is the number of cycles of stress that can be sustained prior to failure.

[37] *Engineering Analysis of Joint Bar Fatigue Life*, D. Y. Jeong, March 2002, (publication pending), U.S. Department of Transportation, Volpe National Transportation Systems Center, Cambridge, Massachusetts.

[38] *Double-shoulder tie plates* fit under the bottom of the rail on top of the wooden tie. The plate has raised areas on the outside and the inside so that the bottom of the rail sits in a groove in the plate. The raised areas are called shoulders.

[39] The *field* side of a rail or rail joint is the side toward the outside of the track.

[40] The *gage* side of a rail or rail joint is the side toward the center of the track.

plate anchor spike. The rail was box anchored at every other tie with Improved Fair anchors. There was no apparent evidence of longitudinal rail or tie movement on either side of the derailment area.

Rail End Batter. The rail end batter was measured[41] for each end of each rail piece described above and pictured in figure 10. Seven ends of rail (pieces 3, 4, 5, and 6) contained rail head deformation adjacent to the cut or broken ends, with the most severe deformation on the butt ends at the east joint. (See figure 12.) No such deformation was noted on pieces 1 or 2. The head on the east end of rail piece 4 (the east end of the plug) was deformed in a manner consistent with trailing rail end deformation.[42] The depth (distance deformed downward) at this location was 0.22 inch. The head of the west end of rail piece 5 (the CWR at the other end of the east joint) was deformed in a manner consistent with receiving rail end deformation.[43] The depth of the receiving rail end deformation for piece 5 was 0.19 inch. The length of both the trailing and the receiving rail end deformation at the east joint butt ends measured 0.75 inch.

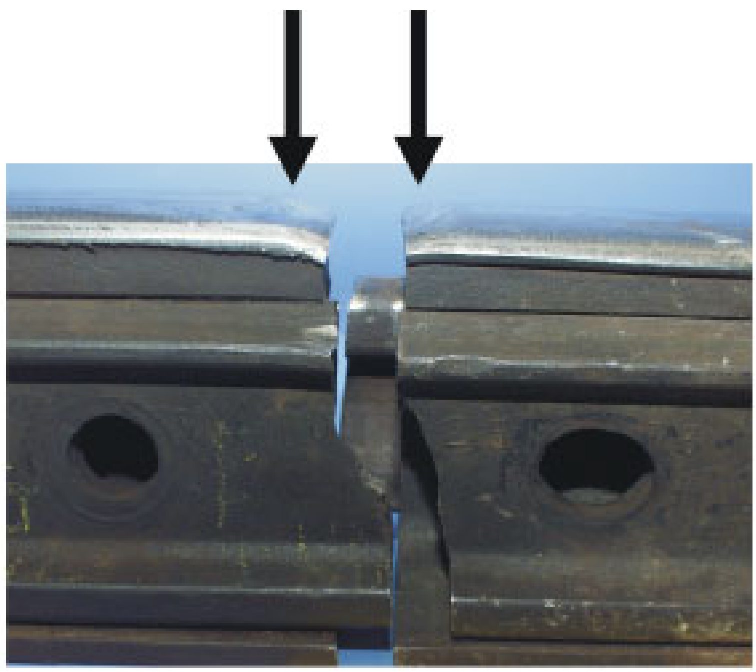

Figure 12. Batter on the accident rail.

[41] The rail deformation was measured with a straightedge placed on top of the head of the rail. These examinations were performed at the Safety Board's Materials Laboratory.

[42] *Trailing rail end* deformation is deformation at the vertical face of the delivering rail end (the end that the wheel traverses just before it leaves one rail and moves to the other rail at a rail joint). It can occur when a misalignment or gap between the two rails allows the wheel to drop off the delivering rail onto the receiving rail.

[43] *Receiving rail end* deformation is an impact deformation on the vertical face of a receiving rail end. It can occur when a misalignment or gap between two rails allows the delivering rail to drop below the surface of the receiving rail so that the wheel hammers against the end of the receiving rail as it rolls over the end corner of the rail.

In addition to the batter to the ends of the rail at the east joint (on pieces 4 and 5), fractured ends on pieces 3, 4, 5, and 6 contained lesser amounts of batter. Table 2 summarizes the length and depth of rail end deformation for these pieces of rail.

Table 2. Postaccident Length and Depth of Rail Head Deformation (inches).

	Rail Piece 3	Rail Piece 4		Rail Piece 5		Rail Piece 6	
	East Fracture End	West Fracture End	East Butt End	West Butt End	East Fracture End	West Fracture End	East Fracture End
Length	0.25	0.19	0.75	0.75	0.25	0.75	0.25
Depth	0.06	0.06	0.22	0.19	0.06	0.09	0.09

Rail Height Differences. The CWR at the east joint had a different amount of head wear than the rail plug, which resulted in a difference in head height at the rail joint. The rail pieces were placed on a level and solid surface and then measured. The difference between the heights of rail piece 4 (the east end of the plug) and rail piece 5 (CWR) was 0.12 inch. Thus, the height of the plug at the east end was higher than the CWR.

Bolt Torque. The CPR's specification for the torque to be used to tighten joint bar bolts was 550 foot-pounds (ft-lbs). When the bolts were removed from the recovered joints, the torque used to loosen the bolts was recorded. (See table 3.)

Table 3. Torque Required to Loosen Bolts on Rail Joints at Point of Derailment.

Bolt			Rail Side of Bolt Head	Torque (ft.-lb.) Required to Loosen
West Joint	A	WEST	Field	Damage to the nut Not measured
	B	↓	Gage	less than 35
	C		Field	Damage to the nut Measured 132
	D	EAST	Gage	391
East Joint	E	WEST	Field	54
	F	↓	Gage	205
	G		Field	126
	H	EAST	Gage	402

Bolt Condition. The eight bolts from the west and east joints were removed and are shown in figure 13. The bolts were inserted into the joint bars alternately from the outside and from the inside. The shank portion of each bolt contained double bending deformation.[44] The bending deformation on each bolt was oriented away from the butt end of the rail joint. This bending deformation is consistent with tensile loading[45] of the rail. The diameter of the shank portion of each bolt in areas that contained no evidence of deformation measured between 0.98 and 1.01 inch, consistent with a 1-inch nominal diameter bolt.

Figure 13. The eight bolts that fastened the joint bars. The disassembled bolts, washers, and nuts are positioned as they were when in place. Note that the shank portion of the bolts are bent away from their rail joints.

The shank portion of each bolt also contained fretting[46] damage that corresponded to contact from the web portion of the rail. (See figure 14.) Fretting damage was most severe on the side of the bolt that was nearest the joint. Fretting damage on the diametrically opposite side of the bolts was minor. Additionally, the neck portion of all the

[44] *Double bending* (sometimes called *crank shafting*) is localized deformation in a straight rod where the deformed portion deviates from a straight line. The deformed portion typically is offset from the axis but remains parallel to the axis.

[45] *Tensile loading* is a condition in which a material is stretched between two points. For example, a length of rail exhibits shrinkage as temperature is decreased, and as a result of this shrinkage, the rail and joint bars located between the rail pieces are subjected to stretching forces.

[46] *Fretting* is a type of wear that occurs between tight-fitting surfaces subjected to cyclic relative motion of extremely small magnitude.

bolts and the shank portion of the bolts that contacted the holes of the joint bars showed fretting damage all around the bolts.

Figure 14. The shiny areas indicate fretting damage on the bolts that fastened the accident joint bars.

Regulatory Oversight of CWR

FRA regulations (49 CFR 213.119, "CWR, general," effective September 28, 1998) required railroads to submit, by March 22, 1999, a maintenance program covering CWR. The FRA was to review the railroads' CWR programs to determine if they contained adequate written procedures to address the regulatory requirements regarding CWR installation, adjustments, maintenance, and inspection and that they included training programs for the people responsible for implementing those procedures. The regulatory requirements generally address rail anchoring and the practices to eliminate rail pull-aparts and buckled track. The CWR regulations do not address joint bar inspections in CWR track. If a railroad's program did not adequately address all the required items, the FRA could return the program and ask for a more complete version. The CPR submitted its CWR program to the FRA on July 8, 1999.

According to FRA representatives, before the January 2002 accident, the FRA had not compared the program the CPR submitted with its list of minimum requirements.

There also was no record of the FRA's having told the CPR whether its CWR program had been received or whether it was acceptable or needed revision. Further, neither the FRA track inspector nor the regional track specialist for the Minot territory had a copy of the CPR's CWR program before the accident.

The CPR's standard procedures for track maintenance were contained in written instructions called *Standard Practices Circulars* (SPCs). Four of these specifically addressed CWR, and it was these four that the CPR submitted to the FRA as documentation for its CWR program:

SPC 6 - Prevention of Track Buckling

SPC 12 - Laying Continuous Welded Rail

SPC 28 - Track Maintenance of Continuous Welded Rail

SPC 40 - Gauge Restraint Measurement System

SPC 12 references at least nine SPCs that the CPR did not provide to the FRA as part of its CWR program.[47] SPC 28 refers to at least five SPCs not provided to the FRA. At the Safety Board's public hearing on this accident, the FRA regional track specialist for the region that includes the accident location stated that when the FRA track inspector in Minot asked for a copy of the CPR's CWR program after the accident:

> … He [the Minot track inspector] was sent—CPRR or SPC 28 and was told that that was the program. And, of course, when you open SPC 28 and start looking at it, it refers to other SPCs, and as far as I'm concerned, if you have a CWR program and you open it up and it refers to another SPC, then that other SPC should be part of the program and should have been with that package, and it was not. And of course, when you sent just one SPC, that's not the complete program.

As an example, the following are excerpts from SPC 12 and SPC 19. Only SPC 12 was submitted to the FRA as part of the CWR program; it contains references to SPC 19, which was not submitted.

SPC 12 - Laying Continuous Welded Rail

3.2 Use of Anchors

c. Use following procedures when anchoring CWR …

For replacement rails, apply and box rail anchors at every second tie in both directions.

Where continuous welded strings are connected to jointed rails, apply and box anchors at every third tie on the jointed rail. When required, install

[47] SPC 7 - Ballast, SPC 8 - Ties, SPC 9 - Rail, SPC 10 - Laying Bolted Rail, SPC 13 - Thermite Welding, SPC 14 - Joints and Bolts, SPC 17 - Gage of Track, SPC 18 - Spiking, and SPC 19 - Rail Anchors.

additional anchors to prevent track movement. (See SPC 19, Rail Anchors.)

SPC 19 - Rail Anchors

2.0 Installing and Maintaining Rail Anchors

For those joints created in CWR through the process of cutting in rails, box anchor every tie for the first 195 feet on either end of the strings that butt up to the newly installed rail.

FRA Track Inspections

After the derailment, the FRA inspected the track on several CPR subdivisions. Three FRA inspectors inspected the track in the CPR's Portal Subdivision from the Canadian border to the North Dakota and Minnesota border and compared it to the CWR program submitted by the CPR. Those inspections began on January 25, 2002, and ended about February 8, 2002. The three inspectors noted 1,858 track conditions they considered to be deficiencies. Of these, 1,847 were written under FRA code 213.119.02, "failure to comply with written CWR procedures." The inspectors alleged that the procedures had not been complied with in that, while the written procedures required that rail anchors be applied box style on every tie for 195 feet on either side of a rail plug, in practice (as at the accident site), box anchors were applied to only every other tie. This anchor pattern accounted for the 1,847 alleged deviations from the written procedures. Ten other alleged deficiencies involved either broken rails or cracked joint bars. The remaining alleged deficiency was for failure to comply with the regulation covering roadway worker protection.

The FRA issued a "Special Notice of Repairs" enforcement action to the CPR on January 31, 2002, for the Carrington and Portal Subdivisions. The agency issued a second notice on February 1, 2002, for the Elbow Lake, Portal, and Carrington Subdivisions. The notice mandated that the railroad reduce the operating speed in those subdivisions from between 40 and 49 mph to 25 mph for failure to comply with written CWR procedures.

FRA Review of Inspection Records

FRA personnel reviewed the CPR's track inspection records in Minneapolis from February 5 to 8, 2002. The FRA identified the following 321 alleged record-keeping deficiencies during that review:

- 175 written under FRA code 213.241.01 for "failure to keep records as required."
- 131 written under FRA code 213.241.04 for "failure of inspector to provide the required information."

- 8 written under FRA code 213.241.05 for “failure of rail inspection record to provide the required information.”
- 7 written under FRA code 213.241.03 for “failure of inspector to sign report.”

CPR Maintenance Practices and Training

Standard Practices.

The CPR’s track maintenance SPCs and actual standard practices were addressed in the July 2002 public hearing. The track foreman stated that when he replaced a rail in CWR territory, the maintenance standard he used for guidance in doing the job correctly was “the old Soo Standard, the way it was done.” He also stated that he was “kinda going by both, the SPC and add a little bit—because that’s what we’re kind of used to going by.”

Training

Training on the SPCs, according to the track maintenance supervisor, occurred in June 2000. This was referred to as “rollout” training to introduce the SPCs that were effective April 1, 2000. Before that, the CPR gave training on track maintenance procedures in 1998. Training covering the SPCs was also conducted “about a month” after the accident and before the public hearing was held in July 2002.

At the public hearing, the section foreman who made the May 2002 replacement rail repair was asked to describe the training for the rollout. He said he thought it occurred in 1999. About the content of the training he said, “I can’t remember all about it….” He was unable to relate any of the subjects covered. He also was asked about the training that had occurred after the accident. Specifically, he was asked about the topics that were covered; he said, “We talked about different topics. I can’t remember what they all were.”

The Safety Board’s review of the CPR’s training records indicated that the section foreman and the track maintenance supervisor had attended an average of five training classes each year between 1997 and 2002, with most of them being 1 day or less, including rollout training.

Anhydrous Ammonia

Anhydrous ammonia (NH_3) is transported as a liquefied compressed gas in pressurized rail tank cars. If it is released, it vaporizes and expands rapidly to return to a gaseous state. The boiling point of anhydrous ammonia is -28° F.

The vapor pressure[48] of anhydrous ammonia at selected temperatures is as follows:

70° F	131 pounds per square inch, absolute (psia)
40° F	74 psia
30° F	60 psia
0° F	30 psia

Under DOT regulations, (49 CFR Parts 171–180), anhydrous ammonia is classified and regulated for domestic shipments as a nonflammable gas but is designated an “inhalation hazard.” At the time of the accident, under Canadian regulations it was classified and regulated as a “corrosive gas” for shipments within Canada. Under international standards and for international shipments, anhydrous ammonia is classified as a “poisonous gas by inhalation.”

According to *Medical Management Guidelines for Acute Chemical Exposures to Anhydrous Ammonia*, issued by the U.S. Department of Health and Human Services’ Agency for Toxic Substances and Disease Registry,[49] anhydrous ammonia has the following health effects:

> Ammonia is highly irritating to the eyes and respiratory tract. Swelling and narrowing of the throat and bronchi, coughing, and an accumulation of fluid in the lungs can occur.
>
> Ammonia causes rapid onset of a burning sensation in the eyes, nose, and throat, accompanied by lacrimation [discharge of tears], rhinorrhea [runny nose], and coughing. Upper airway swelling and pulmonary edema may lead to airway obstruction.
>
> Prolonged (more than a few minutes) skin contact can cause pain and corrosive injury.

According to the Centers for Disease Control and Prevention’s National Institute for Occupational Safety and Health (NIOSH), the low lethal concentration (LC_{LO})[50] of anhydrous ammonia for humans is 5,000 parts per million (ppm) for a period of 5 minutes. NIOSH also stipulates that the IDLH[51] (immediately dangerous to life or health) of anhydrous ammonia is 300 ppm. The odor of anhydrous ammonia can be detected by humans at 3 to 5 ppm.

[48] The vapor pressure of a liquefied compressed gas is the pressure exerted by vapors in equilibrium over the liquefied form in a closed container. Vapor pressure thereby provides a measure of internal tank pressure when the liquefied gas is at a given temperature.

[49] See <http://www.atsdr.cdc.gov/> for the complete guidelines.

[50] The lowest concentration of a substance that has been reported to have caused death in humans.

[51] NIOSH, in its “Respirator Decision Logic,” defines *IDLH exposure condition* as a condition that poses a threat of exposure to airborne contaminants when that exposure is likely to cause death or immediate or delayed permanent adverse health effects or prevent escape from such an environment.

Loading and Shipping

Each of the tank cars was loaded by Canadian Fertilizers Limited with between 29,000 and 29,800 gallons of anhydrous ammonia and was consigned to Canadian Fertilizers Limited in Spencer, Iowa, and Garner Ammonia Terminal, Garner, Iowa. The anhydrous ammonia was loaded at 40° F.

Estimated Tank Shell Temperatures

Heat loss/gain calculations were performed by Trinity Industries, the manufacturer of 5 of the 15 ammonia tanks involved in the derailment, to estimate the temperature of the anhydrous ammonia and the tank shells that catastrophically ruptured in the accident. The calculations estimated the heat loss or gain for a DOT specification 105J300W tank car (105) with two layers of insulation (ceramic fiber and 0.75 lb. fiberglass) and for a DOT specification 112J340W tank car (112) with one layer of ceramic fiber insulation. These physical parameters were similar to those of the tank cars involved in the derailment. The calculations assumed that the tank cars were exposed to an average of -8° F ambient temperature and were loaded with the product at 40° F on January 15, 2002. It was also assumed that because the tanks were insulated to minimize heat loss and gain through the tank wall, the temperature of a tank shell would be nearly equal to the temperature of the liquefied ammonia.

For the five tank cars, the calculated temperatures of both the anhydrous ammonia and the tank car shells at the time of the accident were determined to be 36° F for the class 105 tanks and 30° F for the class 112 tanks.

Also, on-scene measurements of the internal tank pressures of the intact anhydrous ammonia tank cars were about 55 pounds per square inch, gauge (psig). Based on vapor pressure-temperature data for anhydrous ammonia, a pressure of 55 psig would correspond to a temperature of 37° F of the anhydrous ammonia in the tank car.[52]

Loss of Lading From the Derailed Tank Cars

Almost 221,000 gallons of anhydrous ammonia were released from 11 of the tank cars that derailed. Five tank cars (cars 19, 20, 22, 23, and 24) instantaneously lost all of their contents, approximately 146,700 gallons, when each tank car sustained complete fracture and separation of its shell during the derailment. Additionally, approximately 74,000 gallons of anhydrous ammonia were released over 5 days from six other derailed anhydrous ammonia tank cars, PLMX 4644 (car 18), GATX 49248 (car 21), GATX 58659 (car 25), GATX 49285 (car 26), GATX 48004 (car 28), and GATX 48103 (car 31). The remaining four derailed anhydrous ammonia tank cars retained their contents. There were no reports of hazardous materials released from any of the other tank cars. (See table 4.)

[52] "Storage and Handling of Anhydrous Ammonia" by Tanner Industries, Incorporated.

Table 4. Tank Car Damages.

Tank Car Position in Train – ID #	Ammonia Loaded (Gal.)	Damages	Product Lost	Normalized Steel Shell	DOT Specification
18 – PLMX 4644	29,776	Puncture and tear	100% (leak)	No	105J300W
19 – GATX 47814	29,528	Catastrophic rupture	100%	No	105J300W
20 – GATX 47837	29,473	Catastrophic rupture	100%	No	105J300W
21 – GATX 49248	29,447	Puncture	100% (leak)	No	105J300W
22 – GATX 47982	29,481	Catastrophic rupture	100%	No	105J300W
23 – GATX 48081	29,213	Catastrophic rupture	100%	No	105J300W
24 – PLMX 4504	29,006	Catastrophic rupture	100%	No	105J300W
25 – GATX 58659	29,489	Damaged Fittings	Minimal (small leak)	Yes	112J340W
26 – GATX 49285	29,461	Damaged Fittings	Minimal (small leak)	No	105S300W
27 – GATX 58718	29,531	None	None	Yes	112J340W
28 – GATX 48004	29,097	Damaged Fittings	Minimal (small leak)	No	105S300W
29 – GATX 48529	29,222	None	None	No	105S300W
30 – GATX 47822	29,444	None	None	No	105J300W
31 – GATX 48103	29,500	Hidden crack or tear	~50%	No	105J300W
32 – NATX 35798	29,474	None	None	Yes	112J340W

Tank Cars

Tank Car Damage

Derailed freight cars 8 through 17 formed a wall that blocked and ultimately stopped the forward motion of the 15 tank cars carrying anhydrous ammonia. The damage to the anhydrous ammonia tank cars was categorized as ranging from severe to light, generally with decreasing amounts of damage with increased distance from the front of the train. (See appendix F for a detailed description of tank car damage.)

During the derailment, the first seven of the derailed anhydrous ammonia tank cars rotated laterally and separated from their couplers and came to rest aligned perpendicular to the tracks. Five of these tank cars received sidewall impacts to their shells, and the shells structurally failed. Four of these tank car shells sustained fractures that propagated completely around their circumferences. (See figure 15.) The fifth tank car, GATX 47837 (car 20), sustained a fracture that propagated partially around the shell and through the head, resulting in the separation of the tank head from the tank car. Metallurgical examinations showed that the head contained a ductile fracture that propagated from a brittle fracture in the shell portion. Also, within this group of seven severely damaged tank cars, two tank cars, PLMX 4644 (car 18) and GATX 49248 (car 21), received localized shell punctures from derailing debris; however, these punctures were contained in the immediate area of impact, and the cracks did not grow farther into the shells. As a result, these shells partially retained their contents after derailing. However, they vented ammonia at atmospheric pressure for several days, eventually losing all their contents.

Figure 15. GATX 47814 (car 19), above, and GATX 47982 (car 22), below, sustained catastrophic shell fractures. Car 22 hit the house visible behind and to the left.

The next four tank cars carrying anhydrous ammonia, cars 25 through 28, received substantial damage, primarily to their fittings, valves, and connections located in the dome housings on top of the tank cars, with the result that three cars in this group leaked for 5 days during wreck-clearing operations. Visual examination of the draft gear components[53] of these tank cars indicated that the components sustained varying degrees of damage and separated from the shells without tears into the shells. GATX 58659 (car 25) and GATX 58718 (car 27) had normalized[54] shells.

The remaining anhydrous ammonia tank cars, cars 29 through 32, received mostly minor damage to their outer jackets[55] with the exception of car 31 (GATX 48103), whose shell was cracked or torn at one end. The shell of NATX 35798 (car 32) received only minor outer jacket damage with no apparent shell separation; the tank shell was normalized TC128B steel.

Design and Construction

The shell of a tank car is made from rolled plates of steel that are welded to form a cylinder. The tank heads are welded to the ends of the cylinder to form the completed tank. A stub sill—the structural member for the couplers and draft gear and the attachment point for the wheel sets for the tank car—is attached to the underside of the tank at both ends of the tank. Other appurtenances, such as brake system components, are welded to pads that are in turn welded to the tank shell to improve stress distribution.

The 15 tank cars that derailed in this accident were approximately 33,000-gallon capacity DOT class 105 and 112 tank cars constructed with TC128 Grade B (TC128B) steel. Of the 15 tank cars, 12 originally were built as DOT specification 105A300W tank cars in the 1970s but were converted in the 1980s to DOT specification 105J300W or 105S300W tank cars.[56] The tank heads for the class 105 tank cars were TC128B steel ("normalized" during the heat forming process), whereas the cylindrical tank shells for these tank cars were constructed of non-normalized TC128B steel. (All pressure tank cars, including the class 105 and 112 tank cars, built since January 1, 1989, have been required to have tank shells and heads constructed of normalized steel.) The three remaining tank cars were DOT class 112J tank cars that were constructed in the late 1990s; as required, the heads and the shells of those cars were normalized TC128B steel. The five tank cars that had catastrophic shell failures in the Minot accident were built before 1989 and had

[53] Draft gear components make up the railroad equipment attached to the tank to allow the tank car to couple to other railroad cars.

[54] See the "Tank Cars" section of this report for a discussion of normalized versus non-normalized steel. Since 1989, pressure tank car shells have been required to be fabricated from normalized steel. In discussions of the cars involved in this accident, references to cars as being made from normalized or non-normalized steel are based on the dates of manufacture of those cars, not on actual testing of the shell material.

[55] A *jacket* is a steel skin on the outside of the tank. Often there is a layer of insulation between the jacket and the tank car shell.

[56] The DOT specification 105A300W tank car is an uninsulated carbon steel pressure car equipped with top and bottom shelf couplers with manway loading and unloading fittings rated for a tank pressure of 300 psig. The DOT 105S300W tank car specification is a DOT 105A300W equipped with head protection, and the DOT 105J300W is a DOT 105A300W equipped with both head protection and thermal protection.

tank shells fabricated from non-normalized TC128B steel. Also in the train were 10 liquid petroleum gas cars that did not derail. Six of these were built in 1988 or before; four were built after 1988.

Brittleness of Tank Car Steels

The ability of most steel alloys to resist fracturing changes with the temperature of the steel. With a decrease in temperature, ductile steel becomes brittle and is more easily fractured. The change from ductile to brittle does not occur at a specific temperature. Instead, the steel changes from ductile to brittle over a temperature range, and the ductile characteristic gradually becomes brittle. Ductile steel will deform before it fractures. In contrast, brittle steel shows no evidence of deformation and, upon breaking, will exhibit a flat fracture. Less impact energy is required to break brittle steel than to break the same steel when it is ductile. The chemistry, heat treatment, and rolling process determine the temperature at which the steel will change from ductile to brittle (called the ductile-to-brittle transition temperature, or DBTT) and the amount of energy required to cause fracture.

A normalizing heat treatment is one method of lowering the DBTT. This heat treatment also increases the level of energy absorbed as the steel fractures.

Tank Shell Fractures

The five anhydrous ammonia tank cars that sustained catastrophic shell fractures were studied after the accident. Extensive brittle fractures were found in the shell portions of four of these tank cars—GATX 47837, 47982, and 48081, and PLMX 4504. Based on the presence of brittle fractures, these tanks were exposed to a temperature lower than the DBTT at the time of the derailment.[57] The tank shell of the fifth tank car, GATX 47814, was ductile at the time of derailment, but, because of anisotropic[58] properties in the steel, was vulnerable to low-energy fracture propagation that extended around the circumference of the tank car.

Tank Car Steel Testing

To determine the brittleness, or impact resistance, of the steel of the tank cars, samples of the steel were subjected to the Charpy V-notch impact test at different temperatures.[59] The results of this test show graphically how a material makes the transition from ductile to brittle behavior with a decrease in temperature.

Charpy V-notch test specimens, called coupons, were made from pieces of steel cut from the tank cars GATX 47837, 47982, and 47814 and PLMX 4504. Additional

[57] The method of determining DBTT is discussed in appendix E. Further discussion of DBTT is in "Tank Car Steel Testing."

[58] *Anisotropic* means having properties that vary according to the direction in which they are measured. As it applies to this steel, tensile testing did not show much difference in the strength of the material when it was tested in the transverse and longitudinal directions, but the Charpy V-notch impact values showed a large variation between the two orientations.

[59] See appendix E for details of the Charpy V-notch impact test.

specimens from the shell of GATX 47982 were normalized and then prepared for Charpy V-notch testing.

Each test specimen was broken at a specified temperature between -150° F and 212° F to generate a transition curve. A transition curve was prepared for selected coupons by plotting the temperature at which a specimen was tested against the impact energy that was absorbed as the specimen fractured. A DBTT was then derived from the constructed curve. Such curves typically have upper and lower shelves where the energy required to break the specimen remains nearly constant relative to temperature. For the purposes of this report, the DBTT was defined as the temperature corresponding to the average of the energy of the upper and lower shelves.

Charpy V-notch impact specimens oriented parallel to the direction of rolling (longitudinal specimens) and perpendicular to the direction of rolling (transverse specimens) were tested. The graph in figure 16 shows 4 of the 10 transition curves that were generated. The four curves were selected to show the effect of specimen orientation (longitudinal versus transverse) and the normalizing heat treatment on the DBTT and on the energy absorbed. The transition curve for coupon “22-3 long” is for longitudinal Charpy V-notch specimens that were not normalized. The transition curve for coupon “22-3 transv” is for transverse specimens that were not normalized. The transition curves for coupons “22-3 long Normalized” and “22-3 transv Normalized” show the results for longitudinal and transverse specimens after normalizing the same material. The curves for the transverse specimens are representative of the energy that is required to cause fracture around the circumference of a tank shell because the shells are constructed with the direction of rolling of the material around the circumference. As can be seen in figure 16, the transverse specimens that were not normalized generated lower impact energies over most temperatures than the longitudinal specimens.

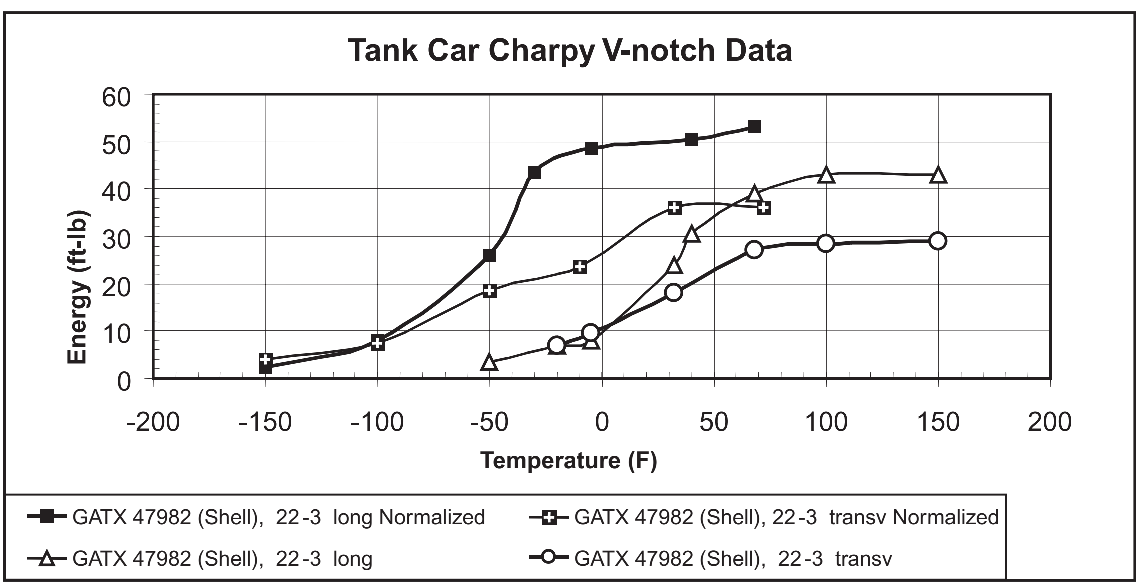

Figure 16. Ductile-to-brittle transition temperature curves generated by Charpy V-notch tests for a shell sample that was removed from tank car GATX 47982.

Assuming that the tank car shell was at a temperature of approximately 36° F at the time of the accident, the "22-3 long" curve shows that the impact energy associated with a crack propagating along the length of the shell is 28 ft-lbs, and the "22-3 transv" curve shows that the impact energy associated with a crack propagating around the shell is 20 ft-lbs. The curves also show that, at 36° F, the normalized specimens fracture in a ductile manner with a significant increase in the impact energy, up to nearly 50 ft-lbs for a longitudinal specimen and 36 ft-lbs for a transverse specimen.

The impact energies required to break specimens from nearly all of the tested head portions at 36° F were much higher than those required to break the non-normalized shell specimens. The higher impact energy required and the ductile fractures of the heads are typical characteristics of heads that were hot formed at normalizing temperature.

Results of Other Charpy V-Notch Impact Tests

In September 1991, the National Institute of Standards and Technology (NIST) prepared report No. 24 that showed properties of normalized TC128B steel.[60] The steel supplied for the NIST testing program was produced according to the Association of American Railroads (AAR) TC128B specification, with lower sulfur content (between 0.008 and 0.010 weight percent) than the sulfur content of the ruptured tank cars at Minot (between 0.02 and 0.03 weight percent). According to the NIST report, Charpy testing of the TC128B steel in the normalized condition showed that the DBTT for specimens oriented in the longitudinal and transverse directions were approximately 10° and 20° F, respectively. At 36° F (the estimated temperature of the class 105 tank shells in the Minot accident) the longitudinal NIST specimens required 120 ft-lbs to fracture; the transverse NIST specimens required 55 ft-lbs to fracture. These impact values are even higher (by as much as 135 and 53 percent, respectively) than the impact values from the test specimens of coupon 22-3 that were normalized. The DBTTs in the NIST test program also were below the temperature of the steel from the ruptured tank cars at the time of the Minot accident.

Tensile Tests and Chemical Composition

According to the AAR certificates of construction for the five tank cars that catastrophically ruptured, the shell and head portions are to be made from TC128B steel. Properties of TC128B steel, including the tensile strength, are specified in the AAR *Tank Car Manual*, M-1002, as supplemented by requirements in American Society for Testing and Materials (ASTM) A20, *Standard Specification for General Requirements for Steel Plates for Pressure Vessels*. Tensile testing of the tank car materials involved in the accident showed that all of the shells and heads met the tensile strength requirements. AAR M-1002 specifies that tensile tests must be performed with the length of the specimen oriented perpendicular to the rolling direction (transverse orientation), which is the weakest direction of as-rolled steels. The measured tensile values of the specimens that were oriented perpendicular to the rolling direction were lower than those for specimens that were oriented parallel to the rolling direction (longitudinal orientation).

[60] NIST Report No. 24 (NIST IR 4660), "Mechanical Properties and Fracture Toughness of AAR TC128 Grade B Steel in the Normalized, and Normalized and Stress Relieved Conditions," by George E. Hicho and Donald E. Harne.

Chemical analysis of the tank car materials showed that the chemical compositions were within the range specified for TC128B steel. Furthermore, the shell and head portions of the tank cars contained no evidence of corrosion degradation.

Welds

Examination of the tank cars at the accident site showed that none of the fractures originated at a weld. When a tank car is subjected to impact, a brittle fracture can prematurely initiate from a weld if the weld has a much higher hardness than the shell. The hardness of the weld and heat-affected zone from a sample from tank car GATX 47814 was comparable to that of the surrounding base metal.

Comparison of Ductile and Brittle Behavior of Normalized and Non-Normalized Steel

Safety Board investigators sought information about the occurrence and impact of brittle fractures in tank cars and the behavior of normalized steel compared to non-normalized steel. Investigators reviewed AAR Tank Car Committee[61] (TCC) correspondence and records and research reports dating to the early 1980s regarding the efforts of the tank car industry to develop and improve the steels used in the construction of railroad tank cars. During the NTSB public hearing on July 16, 2002, parties also provided information regarding ductile and brittle behavior of normalized and non-normalized steels.

Characteristics of Brittle and Ductile Failure

In their description of brittle and ductile fracture initiation during the Safety Board's 2002 public hearing, members of the tank car panel who represented current and past manufacturers and/or fleet owners noted that brittle metals can result in the complete fracture of the tank and the instantaneous release of its cargo. The vice president of engineering of GATX[62] (the builder and owner of four of the tank cars that had structural failures in this accident) added that with a brittle failure, there is usually immediate loss of all the product because of the size of the fracture, whereas with ductile failure, the loss of product usually occurs over a period of time. The director of railcar engineering for Trinity Industries underscored the hazards of brittle failure by stating that in a series of past accidents, brittle tank fragments have been propelled several hundred feet because the lading was a liquefied gas under pressure.

[61] The Tank Car Committee is a standing committee that is responsible for the development and publication of specifications for the design, construction, maintenance, and safe operation of all tank cars used for rail transportation of commodities in North America. TCC members include representatives from the AAR member railroads, tank car shipper/owner organizations, tank car builders, and chemical industry associations.

[62] GATX Rail Division of GATX Financial Corporation, formerly known as General American Transportation Corporation.

The FRA's hazardous materials director further explained that fracture usually begins with a stress riser[63] on some component of the car. Through a dynamic event typically associated with an accident, the stresses may be concentrated in a particular area. However, due to cold temperature and material properties, brittle cracks can be formed and rapidly grow because very little energy is required to propagate this type of failure. In a brittle mode, cracks can propagate at around 7,000 feet per second. As a result, the tank may completely fracture with possible violent dispersal of the tank fragments. Alternatively, to propagate a ductile fracture, energy must be applied continually. Because of the crack-arresting properties of ductile metal, a tank frequently remains intact, and lading losses can take place over an extended period of time.

Industry Actions to Improve Pressure Tank Car Steels

Historically, the TCC has continually monitored and conducted research on the durability and overall performance of various steels used in the fabrication of railroad tank cars. For that purpose, the TCC formed a task force in July 1982 to:

> review all tank car steels as to their suitability in the railroad environment, with a particular reference to the brittle failure potential of the pressure type tank cars under overload stress applied at or below the NDT [nil ductility temperature[64]] values for the steels.

The AAR executive director for tank car safety described this project as a long-term effort to monitor the advances in steel technology and their application to improving tank car steels. A representative from Trinity Industries also noted that the then-chairman of the TCC questioned the continued use of coarse-grained steels and that the January 1982 brittle failure of a class 112 tank car in Austin, Manitoba, also "lent impetus" to this effort. (The tank car involved in the Austin incident was constructed of TC128A, a coarse-grained steel.)

At the October 1982 TCC meeting, the task force reported on its progress and began with a discussion of the Canadian Railway Transport Committee report on the Austin, Manitoba incident. The Canadian report asked for the results of an ongoing study by the AAR and the Railway Progress Institute[65] (RPI) of the number of accidents involving "brittleness problems" in pressure tank cars from 1960 through 1981 and for initiation of an amendment to the AAR *Tank Car Manual*, M-1002:

[63] A *stress riser* is a point or area where stress is concentrated.

[64] *Nil ductility temperature* is defined as the highest temperature at which a fracture will extend through one or both edges on the tension side of the specimen in the drop-weight test (ASTM E-208) that measures the impact resistance of steel. In this test, a weight is dropped on a standard specimen that contains a notched weld. Bending of the specimen is limited by a stop that is located at the bottom of the specimen fixture. The test is repeated for several specimens over a range of temperatures.

[65] The Railway Progress Institute, a rail equipment and supply industry group, in 2003 was consolidated with the Railway Supply Association (RSA), another rail supply industry group, into the Railway Supply Institute, Inc. (RSI).

> providing for mandatory use of steels on all newly built cars with NDTs (nil ductility temperatures) below those which may be expected in Canadian winter service; and amendment of M-1002 to provide for minimum Charpy-V or other test values on NDT or lowest service temperature.

Upon addressing these issues, the task force concluded that research and development of new steels was not a timely approach for determining "which type of fracture is its [the task force's] major aim to prevent." The task force also concluded that -30° F was the lowest service temperature for establishing parameters and that TC128B steel had been and should continue to be the steel of choice for manufacturing tank cars that transport pressurized liquefied petroleum gas (LPG).

At a January 1983 meeting, the task force discussed a draft report that analyzed the types and severity of fractures that had occurred in tank cars in various accidents. The task force decided to review and analyze these accident reports. After reviewing the accident data, the task force met in June 1983 and prepared its final report to the TCC. In its report, the task force noted the following:

- Of the 598 reported lading losses from pressure tank cars over the previous 16 years, 19 involved brittle failures.
- If the tank cars that sustained the 19 brittle failures had been manufactured from TC128B normalized steel, 14 of the brittle failures would have been ductile failures, and only 5 would have been brittle failures.
- Lading losses would still have occurred for all 19 brittle failures if these tank cars had been constructed of normalized TC128B steel.
- Improvements in manufacturing technology, design, and specification requirements for tank cars also would have improved the resistance to lading loss of the 19 failed cars.

The task force concluded that very few cases of brittle failure should be expected in pressure tank cars constructed of either rolled [non-normalized] or normalized TC128B steels as the result of accidents. The task force further concluded that it was not cost effective to construct new pressure tank cars from normalized TC128B or other more "exotic" steels. In October 1983, the TCC unanimously accepted and endorsed the task force report.

In July 1986, the TCC established a new task force to evaluate improvements that had been made to TC128B and ASTM A516 steels. The AAR executive director for tank car safety stated that the purpose of the task force was to assess what improvements to tank car steels could be made in the short term.

In November 1986, the task force reported to the TCC that the greatest improvements to tank steels would be accomplished through normalizing heat treatment. The task force chairman advised the TCC in a November 18, 1986, letter:

> The charge given to this group was to consider near-term improvements that might be made to TC128 and A516 steels.… The focus of the group was on TC128 and pressure tank car tanks in particular, for reasons with which we are all familiar. Our objective, as we understood it, was to devise ways of improving the low temperature toughness of these steels.…

In regard to normalized steels, the letter further stated:

> While all of these measures [limit grain size, reduce carbon, reduce sulfur, lower finishing temperature, and prohibit remelt scrap] would result in some improvement of toughness, it is not clear how much would be gained. It was agreed that the one measure which would result in the greatest improvement would be to normalize the tank steel. We are therefore recommending that this be done.…
>
> … The number of brittle facture cases has not been significantly large when considering the hundreds of ductile punctures and ruptures which have occurred and the thousands of impacts the tanks have experienced. Nevertheless, some reduction in the number of brittle facture cases is predictable with a change to normalization. A reduction in the number of lading loss cases will also occur, but to a lesser extent because in some cases a would-be brittle failure will be converted to a ductile puncture.

The TCC adopted the recommendation in principle in January 1987, but asked the task force to conduct additional research in areas such as welding and repair of normalized TC128B steel. In March 1987, the task force recommended that coarse grained steels be eliminated completely for all tank car construction—pressure and non-pressure cars alike. In June 1987, the task force submitted its final recommendation to the TCC for the revision of section 2.2.1 of M-1002 that would require the use of normalized steel for the tank shells of all pressure tank cars ordered and constructed after January 1, 1989. At its November 1987 meeting, the TCC endorsed the task force report. Further, the 1988 TCC report stated the following:

> The Committee continues to monitor the work that is being done to progress the promising new tank car steels, steels that will remain ductile at the coldest expected operating temperatures.… Evidence of brittle failure has been documented to be minimal; nevertheless, it was agreed that new construction should utilize the current state of the steel manufacturing art.

Research and Accident Data

Since 1970, the AAR and the RPI have jointly sponsored and conducted numerous research studies on the performance of tank car steels, including the following:

- *Fracture Properties of Tank Car Steels – Characterization and Analysis*, RPI-AAR Report RA-03-4-32, August 1975
- *Material Study on Shells Used in Current and Former Tank Car Construction and From Cars Involved in Accidents*, RPI-AAR Report RA-03-5-33, August 1975

- *Analysis of Non-Pressure Tank Car Behavior in Accidents*, RPI-AAR Report RA 02-4-47, March 1983
- *Phase 03 Report on Behavior of Pressure Tank Car Steels in Accidents*, RPI-AAR Report RA 03-6-48, June 1983
- *AAR-RPI Project for Analytical Selection of New Tank Car Steels of Improved Weldability and Fracture Properties*, Summary Report of Project Objectives, May 1985
- *Evaluation of New Steels for Tank Cars*, RPI-AAR RA 03-7-53, April 1987
- *Fracture Behavior of Tank Car Steels in Accidents (1981–1994)*, RPI-AAR Report RA 03-6-62, December 1998

The 1983 reports RA 02-4-47 and RA 03-6-48 covered accidents from 1965 through 1980. Both reports were based on a review of the RPI/AAR accident database. The review that led to Report RA 02-4-47 was conducted to identify areas where practical design changes might lead to reduction of product releases in non-pressure tank cars. The report concluded that a negligible reduction in product releases would have resulted from the design changes considered. The review that resulted in Report RA 03-6-48 was conducted to determine whether steels with improved fracture properties would have been effective in preventing brittle fracture and lading losses in pressure tank cars. Of 595 pressure tank cars damaged in railroad accidents and sustaining lading losses, 16 were deemed to involve brittle fracture. The researchers concluded in the report that if all 16 of these tanks had been fabricated from normalized TC128B steel, the number of lading losses would have decreased from 16 to 11. The researchers also concluded that use of a hypothetical steel[66] with an NDT of -80° F would have decreased the number of lading losses from 16 to 8. The researchers then concluded that a more significant effect on reducing lading losses would come from minimizing the potential for fracture initiation.

The 1998 report, RA 03-6-62, addressed the fracture behavior of tank car steels from 1981 through 1994, with the specific objective of "analyzing data so that the factors contributing to the lading losses due to brittle and ductile fracture can be evaluated and quantified." The same engineering firm that researched and wrote the two 1983 reports was again retained to research and write the 1998 report. The conclusions reached in the 1998 report included the following:

- Of the 13,450 cars damaged, 635 (4.72 percent) experienced lading loss through the head or shell due to either a brittle or a ductile fracture.
- Of the 635 tank fractures, 13 (2.0 percent) of the failures were deemed to have been caused by brittle fracture. The remaining 622 (98.0 percent) failures were judged to have been caused by ductile fracture.

[66] Steel that has an NDT of -80° F as defined in AAR report RA-03-6-62 (R-924).

- If all 13,450 damaged tank car tanks had been constructed of normalized TC128B steel, the probability of a lading loss through the tank head or shell would have been reduced from 4.72 percent to 4.71 percent, or a net reduction of two lading losses.
- If all 13,450 damaged tank car tanks had been constructed of a hypothetical steel with an NDT of -80° F, the probability of a lading loss through the tank head or shell would have been reduced from 4.72 percent to 4.68 percent, or a net reduction of six lading losses.
- The use of normalized TC128B steel or the hypothetical steel described above would provide a minimal reduction in lading losses.

Because the 1998 report is the most current and included analyses of failures of tank cars built after 1988 and therefore constructed of normalized steel, Safety Board investigators made a detailed and thorough review of this report. From this review, Safety Board investigators noted that:

- The report arbitrarily designated cracks with a length of 18 inches or longer as brittle and cracks less than 18 inches long as ductile. The report did not address the technical basis for this criterion.
- The report concluded that the number of lading losses from brittle fractures would not have been significantly reduced, but did not address the effect upon the public of instantaneous releases associated with large brittle fractures versus slower sustained releases over several hours or days.
- The report did not address the potential risks from the complete fracture, fragmentation, and rocketing of tank car fragments, which is typically associated with brittle fractures.

In evaluating the performance of normalized steel in accidents, the Railway Supply Institute stated that from its review of the past 14 years of the AAR-RPI accident database, it has been unable to identify any transportation incident where a normalized tank shell has propagated a brittle crack.

Reduction of Risks and Potential Solutions

In view of both the susceptibility to brittle fracture of non-normalized tank cars, as demonstrated in the Minot release, and the large number of non-normalized tank cars in service, the Safety Board explored during the public hearing possible practices to reduce the risks from these pre-1989 tank cars. Both long- and short-term solutions were discussed. Among the short-term or interim fixes considered for reducing risks and reasons for their rejection were the following:

1. *Increasing cargo loading temperatures to maintain the temperature of the tank shell above the DBTT.* Tank car manufacturers and FRA representatives dismissed this approach as unsafe because the internal pressure of the tank car would increase with heating the product. Higher product temperatures (which in turn cause higher operating pressure) would increase the possibility of release of product from the safety valves, and less product could be loaded per car. Consequently, more tank cars would be required to transport the same amount of product, and this would increase the risk due to higher number of hazardous materials cars and trains in service. Additionally, winter temperatures would cool a tank car in a short period of time to a point where no net change in brittle failure would be achieved.
2. *In-situ normalization of the tank shells of the pre-1989 fleet*. Tank car industry representatives dismissed this approach as too expensive.
3. *Placement of the pre-1989 pressure tank cars to the rear of a train to reduce the magnitude of dynamic accident forces to the section of the train with the ammonia cars*. Industry and FRA representatives dismissed this approach also as too expensive, and they noted the greater risks that would result from increased handling of tank cars in yards and the possible adverse effects on train handling characteristics, which could possibly put other cars in the train in jeopardy.
4. *Reduction in train size and speed to reduce the magnitude of dynamic accident forces*. Industry representatives dismissed this approach as similarly too expensive and operationally ineffective.
5. *Phasing out of non-normalized pressure tank cars to reduce risks*. All members of the tank car panel agreed that it was not justified. Specifically, various members of the tank car panel, the AAR representative, and the FRA's hazardous materials director cited the conclusions of the most current study, RPI/AAR Report, "Fracture Behavior of Tank Car Steels in Accidents (1981–1994), to support their conclusion that based on accident data, non-normalized tanks do not pose a risk because brittle failures are very rare, and use of normalized steel does not significantly reduce lading losses in accidents. One member of the tank car panel stated the following:

> I don't believe that the expenditure of a great deal of money to do this damage tolerance analysis on these old cars is money well spent. I believe you would be better off to apply that money to research for the future and take a look at what are the forces in a derailment in a car, what are the characteristics of some of the new materials.

The participants also proposed at the public hearing the following long-term solutions for reducing risks:

- A better understanding of the forces to which tank cars are subjected under derailment dynamics;
- Continued research to develop improved steels with greater fracture toughness;
- A mechanism or process to evaluate and replace aging equipment with newer, more technologically advanced designs and materials; for example, ranking the existing tank car fleet to identify tank cars with the highest risk; and
- Economic incentives to replace the existing fleet with cars using new tank car construction technology and increasing the tank car weight limit to 286,000 pounds.[67]

The director of railcar engineering for Trinity Industries did express an interest in testing the steels that are manufactured for tank cars more rigorously than required under current standards. He noted, for example, the potential for other elements to be present that are not tested for and that could have detrimental effects. His company has developed an extended standard that includes maximum amounts of about 20 different elements, including elements such as boron, which can have a detrimental effect on steel. He added that his company had instituted quality assurance practices for monitoring steel mills, practices that are not found in any of the existing published specifications. Further, his company requires all of its steel, both normalized and non-normalized, to be impact tested and examined for grain size to meet specific requirements.

In referring to the use of Charpy V-notch tests to verify the impact resistance of the steels used in tank cars, the director of railcar engineering added that Charpy impact tests are currently not required to verify the impact resistance of steels, and he said he believed it would be both simple and inexpensive to add such a requirement.

In response to these comments, the representative of the AAR concurred with conducting the Charpy V-notch tests to verify impact fracture properties and stated that he would bring the matter before the TCC. Furthermore, in the AAR's September 20, 2002, letter to the Safety Board after the public hearing, the AAR representative stated that the TCC has begun analyzing the failure of multiple tank cars in the Minot accident and, as a result, the TCC has formed a task force to review existing tank car designs for their vulnerability to fracture at temperatures below the NDT. He further stated that a second existing task force on tank car steels will "give a high priority to the study of improvements in tank car steels for new construction, including improved material acceptance tests." As part of this effort, this second task force will characterize the types of tests to determine the NDT, recommend changes with respect to qualifying new steels for use in new pressure tank cars, and evaluate the feasibility of establishing a minimum design temperature and grain size criteria. The AAR representative stated that the planned work assigned to these two task forces addresses existing cars and "sets a path" for further improvements in tank car steels.

[67] Under 49 CFR 179.13, tank cars built after November 30, 1970, must not exceed 34,500 gallons capacity or 263,000 pounds gross weight on rail.

Also, in a January 23, 2004, letter, the FRA advised the Safety Board that the Volpe National Transportation Systems Center has developed a preliminary research plan to assess and analyze the forces imparted to tank cars during derailments. The research, which will be funded by the FRA over a period of 2 to 3 years commencing in fiscal year 2004,[68] will involve the development of a model to characterize the forces acting on a tank car shell during impact. The research also will involve the evaluation of the material properties of the tank shell and the application of criteria for predicting the mode of failure of the tank shell in train derailments. Currently, FRA funding to the Volpe Center for hazardous materials research is about $400,000 annually. The FRA expects that approximately half of these funds could be applied to the analysis of derailment forces over the next 2 to 3 years to produce the working model. However, as described in the FRA letter, the research plan is focused only on modeling efforts. There is no discussion in the research plan of any testing to determine the relevant material properties or the range of material properties that could occur during service. There is also no discussion of testing to validate the failure analyses.

Federal Requirements

Following a series of catastrophic brittle tank car head failures in the 1960s, the DOT's Hazardous Materials Regulations Board issued on April 30, 1974, 49 CFR 179.100-8(b) directing that pressure tank car heads be normalized at a temperature between 1550° and 1700° F for a minimum of 30 minutes. That board stated that the proposed changes should improve the material requirements for pressure tank cars constructed from fine-grained steel to ensure that notch-ductility is maintained. Other than the tank car head requirements for normalized material, the DOT has no requirements that tank car shells be normalized. The chief of the FRA Hazardous Materials Division explained at the Safety Board's public hearing that with the AAR standard requiring the use of normalized steel for pressure tank cars from 1989 forward, the AAR standard was an industry law, and therefore it was not necessary for the DOT to incorporate this standard into Federal regulations.

Tank Car Population

During the Safety Board's July 2002 public hearing, an AAR official stated that the North American in-service tank car fleet (tank cars operating in the United States, Canada, and Mexico) totaled about 280,000. Data from the AAR indicated that of these the number of pressurized tank cars (DOT classes 105, 112, and 114) in service was 59,344. Of this number, 23,919 were built after January 1, 1989, and were manufactured from normalized steel. The remaining 35,425 pressure tank cars were built before 1989 and were not required to be constructed with normalized steel. According to one tank car manufacturer, there is no reasonable way of sorting out how many of the pre-1989 pressure tank cars may have been constructed with normalized steel. The consensus of representatives from the tank car industry is that nearly all of the pressure tank cars constructed before 1989 were constructed of non-normalized steel.

[68] Fiscal year 2004 is from October 1, 2003, through September 30, 2004.

A total of 11,175 class 105 tank cars rated for 300 psig and similar to the class 105 tank cars that failed in the Minot accident were in service in 2002. Of these, 6,211 were constructed before 1989 and therefore not likely to have been constructed of normalized steel. Similarly, a total of 24,901 class 112 tank cars with a pressure rating of 340 psig (similar to the class 112 tank cars involved in the Minot accident) were in service in 2002. Of this number, 14,729 tank cars were built before January 1, 1989, and very likely were constructed from non-normalized steel.

During 2000, there were more than 1.23 million tank car shipments of hazardous materials in the United States and Canada, representing about 64 percent of all hazardous materials railroad shipments. Class 2 liquefied compressed gasses (LPG, anhydrous ammonia, chlorine, propane, and vinyl chloride) were among the top ten shipments of hazardous materials commodities transported by tank car. This represented almost 20 percent of all hazardous materials tank car shipments. In 2000, there were almost 55,000 tank car shipments of anhydrous ammonia.

Other Information

Postaccident Actions

On January 20, 2004, investigators discussed with CPR officials the status of several of the issues arising from the Minot accident. According to those discussions and documentation provided by the CPR, since the accident, the CPR has instituted a rail joint bar inspection policy that requires that maintenance workers perform on-the-ground joint bar inspections. The CPR has stated that these inspections will be performed semiannually (spring and fall) and that the results will be documented and forwarded to the local supervisor and division headquarters for data collection and trend analysis.

In addition, the CPR stated that it has re-instituted the ultrasonic rail joint testing program on its U.S. operations from the Twin Cities area west to Portal, North Dakota. The guidelines for those inspections state that the inspections will be performed semiannually. The test results will be forwarded locally and to division headquarters. CPR representatives told the Safety Board they did not believe the joint bar conditions east of the Twin Cities warranted ultrasonic testing.

CPR officials also stated that they were developing a “proficiency testing” program to ascertain the knowledge level of their engineering employees with regard to recent training on engineering practices and procedures. They said they hope to support that goal by completing a 4-day training course for supervisors, which they said would be completed by the first quarter of 2004, with the training to be fully implemented by the third quarter of 2004.

CPR officials provided the Safety Board with a draft of a revised CWR program, which they said is ready to be forwarded to the FRA for its review. The revised program addresses inspection and maintenance issues without cross-referencing other CPR written procedures.

On January 26, 2004, a Safety Board staff investigator met with the FRA's track division chief to discuss the FRA's progress on its review of CWR programs. Data indicated that the FRA had completed its reviews of most major railroads covering about 80 percent of the CWR territory in the industry. The FRA still has about 171 railroad CWR programs to review, the majority of them for smaller, short line operations.

Disaster Preparedness

The chief of the Minot Rural Fire Department has been a volunteer firefighter since October 1980 and has been the chief of the Minot Rural Fire Department since 1987. According to the chief, North Dakota does not have any training mandates for volunteer firefighters. However, the chief requires that all Minot Rural Fire Department firefighters become "Firefighter 1" certified on the Essentials 4 Program[69] within 2 years of joining the department. The chief stated that the Essentials 4 curriculum provides firefighters the basics of fire theory, SCBAs, fire extinguishers, ladders, hoses, nozzles, water supply, and basic training.

The Minot Rural Fire Department volunteer firefighters take training twice each month on various topics related to fire suppression and rescue. A few months before the accident, the Minot Rural Fire Department conducted a "Hazardous Materials Awareness" course for the volunteer firefighters. The chief stated that the firefighters are trained in the use of SCBA, and that the Minot Rural Fire Department has developed and used a standard operating procedure for SCBA use. The chief also stated that area fire departments have worked well together in previous mutual aid situations and that the relationships developed with these local fire departments facilitated the use of a unified command at the emergency operations center.

The local Minot Emergency Responders, the City of Minot, and the CPR hosted an emergency response exercise on September 7, 2001. The exercise involved responding to a hypothetical 200-gallon release of diesel fuel, a damaged and leaking molten sulfur tank car, a release of an undetermined amount of phosphoric acid, and a damaged railcar containing a mixed load of hazardous materials. The purpose of the exercise was to test and evaluate the emergency operations plans and the response preparedness of multiple local, State, Federal, and private response organizations. Further, the response exercise provided an opportunity to test and evaluate the performance of emergency services and support agencies during hazardous materials releases that involved personal injuries and evacuations. Trinity Hospital also participated in this exercise to test its own procedures for managing a hazardous materials accident.

[69] *The Essentials 4th Edition of Firefighting* is a nationally recognized training curriculum, validated by the International Fire Service Training Association and published by Fire Protection Publications at Oklahoma State University. The North Dakota Firefighters Association, which is charged with providing training for firefighters in North Dakota, has adopted this curriculum. The program teaches and evaluates basic firemanship. Firefighter 1 and 2 are the levels attained upon successful completion of the course materials, with Firefighter 2 being the higher of the two levels.

Analysis

Exclusions

The engineer and conductor were qualified in their operational responsibilities, were rested, and were familiar with the territory. The event recorders indicated no abnormalities in train handling, and the train was being operated within the specified speed for the track. The results of postaccident testing of the train crewmembers for alcohol and specific drugs were negative. Therefore, the Safety Board concludes that train crew qualifications and train operation were not factors in this accident, and there was no evidence found that crew fatigue or alcohol or drug use were causal or contributory to the accident.

The review of the preaccident mechanical inspections and repairs that were made to each car and locomotive did not reveal anything unusual. Postaccident mechanical inspection and testing of the equipment was also unremarkable. Each component, car, and locomotive performed as intended.

The wheels on the locomotives, the 3 head-end cars that did not derail, and the 31 derailed cars were examined in detail. The wheels from the derailed cars showed no signs of preaccident distress. All the broken and loose wheels that were found appeared to have been damaged in the accident. Further, the track structure that the train traversed before it reached the point of derailment showed no evidence that a distressed wheel had applied an abnormal load. The circumferences of the wheels on the derailed cars were found to have significant abrasions, which were probably caused by contact with the ballast and track components during the derailment. Therefore, the Safety Board concludes that the derailment was not caused by a mechanical or component failure of any of the train's rolling stock.

The Accident

The operating crew of CPR train 292-16, while traveling about 41 mph, experienced rough track at MP 471.65 just before their train derailed, separated, and went into automatic braking. During the mechanical investigation of the locomotives and first cars on the train, marks were found on the wheels that had traversed the north rail. The marks consisted of a point of abrasion on the tread. Starting with the lead locomotive, the scuff points became more distinct by depth and metal flow until the third car behind the locomotives, which was the last car to traverse the point of derailment without derailing.

When the rail that was disrupted as a result of the accident was recovered and reassembled, pieces of a 36-foot-long piece of replacement rail from the north rail were found. At each end of the replacement rail was a joint connecting the plug to the existing

CWR. The joint on the west end was found intact, albeit bent, but the east joint was found completely separated with the joint bars fractured vertically at the rail joint.

Laboratory examination determined that the east joint bars contained fatigue cracks that existed before the derailment. The bolts that were removed from the joint displayed signs of bending away from the joint in both directions, meaning that the rail had been under tension and that the joint had pulled slightly apart. During reassembly of the rail pieces, investigators found that portions of the railhead had broken out of the rail where the joint bars attached. Later, small fatigue cracks were found that emanated from the bolt holes that had been drilled in the rail to secure the joint bars.

Further examination of the rail ends at the east joint showed signs of batter from impact by the train wheels. Although some batter was found on nearby rail fractures, the batter on the rail ends at the east joint was more severe. The more severe batter on the rail ends in the east joint, the bent bolts, and the abrasions on the wheels of the head portion of the train that traversed the north rail confirmed that a gap existed at the east joint and that the joint bars at the east end of the plug rail had fractured under the previous train or as the accident train passed over the joint. After the joint bars fractured, the rail itself, which had been weakened by small fatigue cracks, also fractured. The Safety Board therefore concludes that the derailment occurred as a result of the joint bars and rail at the east joint of the plug having fractured and broken away.

The dynamic forces sustained as the derailing cars slammed into the cars ahead resulted in the catastrophic failure of five tank cars and the instantaneous release of about 146,700 gallons of anhydrous ammonia. This instantaneous release from these five cars, coupled with the sustained release of an additional 74,000 gallons of anhydrous ammonia from six other tank cars, is among the largest releases of hazardous materials caused by a train derailment and presented a serious hazard to the city of Minot. This release created a larger and more concentrated plume of ammonia than if the same amount had been released gradually over an extended period. Essentially, the release of product from the six other breached tank cars over 5 days allowed the ammonia to disperse and dilute, which resulted in less exposure as the distance from the accident site increased. Consequently, the larger, more concentrated ammonia plume from the five tank cars that catastrophically failed increased the risk of exposure to local residents and resulted in one fatality. The residents in the immediate area of the accident site were also endangered by rocketing tank car parts that hit one house. Therefore, the Safety Board concludes that the catastrophic fracture of five tank cars increased the severity of the accident by exposing residents to high concentrations of toxic vapors from the instantaneous release of 146,700 gallons of anhydrous ammonia and to the rocketing of portions of tank cars.

Joint Bar Failures and Track Maintenance

Fatigue cracking in the joint bars was initiated and propagated by cyclic stress generated each time a wheel passed over the rail joint. A combination of several factors, such as a wider ballast crib, under-torqued bolts, a vertical offset, and a gap between the rail joints, can magnify these cyclic bending stresses in joint bars, and all of these conditions were probably present at the broken joint. The ballast crib at the broken joint was wider than in nearby areas. This caused the ends of the rails to be suspended over a distance that resulted in higher bending stresses. Although the preaccident bolt torque could not be determined absolutely, the disassembly torque on the bolts for the broken joint bars was significantly low, much less than the 550 ft-lbs of tightening force specified by the CPR. The laboratory examination showed that there was a vertical offset of 0.12 inch between the rail heads at the broken joint. Such an offset also increases the impact loading of the joint. The preliminary results of studies conducted at the Volpe Center suggested that variables such as a gap between the rail ends decrease the structural strength of the joint, and the examination of the rail showed that there would have been a horizontal gap between the rail heads of approximately 0.459 inch to 0.659 inch when the rail joint was under tension.

CWR territories typically are associated with higher speed operations, higher tonnage, and greater hazardous materials density, as well as passenger train operations. In signaled territory, signal systems can alert the dispatcher and train crews to the presence of rail discontinuity; however, the final fracture of many rail joint components occurs under train movement. Thus, whether in signaled or dark territory, track inspections to identify and remove cracked rail components before the cracks grow to critical size are the primary preventive measure to ensure safety.

According to CPR maintenance-of-way employees, most inspections of joint bars were visual inspections made from a moving Hy-Rail vehicle. They would also listen for telltale sounds to indicate a loose joint. But neither of these methods is as accurate at detecting defects in the joint bars as a visual inspection from the ground. The sound as the vehicle traverses a joint is both nonspecific and subjective. Inspectors simply cannot "hear" the presence of small hairline cracks at a rail joint location. A wide gap at the rail ends may be detected as a "thud," but these gaps are more closely associated with pull-aparts.

Visual inspection from a moving vehicle is inadequate because, for example, a track inspector checking the accident location from a vehicle traveling west to east would be able to see only the tops of the joint bars on the north rail, and the outside joint bar on the south rail would not be visible at all. Even those joint bars that can be partially seen by an inspector may have small fractures or fatigue cracks that are extremely difficult, if not impossible, to see from a moving vehicle. Instead, to adequately visually inspect joint bars, an inspector must dismount the vehicle and conduct an up-close, on-the-ground inspection of both the field- and gage-side bars for small hairline cracks. The joint bar fatigue cracks that eventually fractured and led to the Minot derailment were externally visible over a length of 1.9 inch on the gage-side bar and 0.8 inch on the field-side bar. An on-the-ground, visual inspection of this joint bar would almost certainly have detected the larger crack, which should have led to replacement of the joint bar before it failed and caused a derailment. A secondary benefit of on-the-ground rail joint inspection in CWR territory is that the inspector could assess the rail joint gap as well as look for evidence of bent or loose bolts.

At the time of the accident, the CPR's inspection program required an on-the-ground inspection of joint bars only once per year. Given the increase both in tonnage and in the number of joints on the accident subdivision as well as the minimal amount of specific guidance provided for joint bar inspection, the Safety Board concludes that CPR inspection procedures before the accident were inadequate to properly inspect and maintain joints within CWR, and those inadequate procedures allowed undetected cracking in the joint bars at the accident location to grow to a critical size.

Since the accident, the CPR has instituted a rail joint bar inspection policy that requires that maintenance workers perform on-the-ground visual joint bar inspections semiannually (spring and fall) and that the results be documented and forwarded to the local supervisor and division headquarters for data collection and trend analysis. In addition, CPR officials stated that the railroad has reinstituted ultrasonic rail joint testing on tracks from the Twin Cities area west to Portal, North Dakota. Guidelines state that the ultrasonic inspections will be performed semiannually and the results will be forwarded to the local supervisor and to division headquarters.

The FRA's regulations regarding CWR are silent on inspections of joint bars. Although, by definition, CWR joints are welded rather than being bolted with joint bars, in practice, a length of CWR can have numerous joint bars where rail plugs have been added to replace defective rail sections. Although FRA regulations state that cracked or broken joint bars shall be replaced, they do not provide any guidance on finding such joint bars. Defects such as fatigue cracks develop and grow over time until, as in this accident, the bar can no longer support the load and fractures. With the proper frequency and type of joint bar inspections—specifically, on-the-ground visual inspections—these defects can be detected, and the defective bars can be repaired or replaced before their minor defects lead to complete failure and a possible derailment. Moreover, as noted previously, on-the-ground visual inspections can detect rail gaps, loose bolts, poor joint support, or other conditions that can be corrected before cracking develops. Unfortunately, a railroad can meet existing FRA CWR regulations without an effective joint bar inspection program. The Safety Board concludes that FRA requirements regarding rail joints in CWR track are ineffective because they do not require on-the-ground visual inspections or nondestructive testing adequate to identify cracks before they grow to critical size and result in joint bar failure. The Safety Board therefore believes that the FRA should require all railroads with CWR track to include procedures (in the programs that are filed with the FRA) that prescribe on-the-ground visual inspections and nondestructive testing techniques for identifying cracks in rail joint bars before they grow to critical size. Further, the Safety Board believes the FRA should establish a program to periodically review CWR rail joint bar inspection data from railroads and FRA track inspectors and, when determined necessary, require railroads to increase the frequency or improve the methods of inspections of joint bars in CWR.

Training and Written Instructions

The CPR SPCs that were used to standardize the procedures used by the maintenance-of-way employees were confusing. With the SPCs' imbedded references to other SPCs, an employee easily could be confused and unable to apply the proper procedure. One SPC specifically states that the anchor pattern should be "every other tie," while a conflicting SPC instructs the employee to anchor at "every tie for 195 feet." The Safety Board concludes that the CPR's track procedure manual was confusing and thus did not provide employees with clear guidance on the practices to be followed in installing and maintaining CWR.

FRA preamble language explaining the CWR regulation states that a railroad's CWR program "procedures should be clear, concise, and easy to understand by maintenance-of-way employees." The CPR provided the Safety Board with a revised draft of its CWR program in January 2004 that CPR representatives said was intended to provide clearer and more concise instructions. The CPR advised the Safety Board that it plans to file the revised CWR program with the FRA.

The CPR had trained its track employees on the SPCs, including 1 day of rollout training to introduce the SPCs. However, responses at the public hearing to questions about the training indicated that at least one employee could not recall the particulars of training presented just 2 months before and that one employee used a combination of the CPR's and the old Soo Line's methods for track maintenance.

The Safety Board believes that the CPR should finalize and submit to the FRA its revised CWR program and ensure that all its maintenance employees are trained in the requirements of the new program.

Federal Railroad Administration Oversight

In accordance with the FRA's CWR regulations, the CPR submitted its CWR program to the FRA in July 1999. But the FRA had not reviewed the CPR's CWR program before the accident in January 2002.

Also, according to the FRA inspector and the track specialist for the Minot area, they did not have a copy of the CPR's CWR program before the derailment. Consequently, no comparison could be made between the program standards and actual conditions. A review after the accident showed widespread deviations between the two, necessitating a slow order of 25 mph for all trains. The Safety Board therefore concludes that the FRA's oversight of the CPR's CWR program was ineffective because the agency neither reviewed the program nor ensured that its track inspectors had copies of the program to determine if the railroad was in compliance with it.

The Safety Board believes that the FRA should instruct FRA track inspectors to obtain copies of the most recent CWR programs of the railroads that fall within the inspectors' areas of responsibility and require that inspectors use those programs when conducting track inspections.

Tank Car Performance

Catastrophic Tank Shell Failures

Of the 31 cars that derailed, the first 17 rotated laterally, "folding" alternately left and right, leaving the 8th through 17th derailed cars resting across the track. These 10 cars aligned across the tracks and compacted against each other, creating a wall for the remainder of the train to strike. Under the continuing momentum of the trailing cars of the train, the 18th through 24th cars (the first 7 anhydrous ammonia cars) continued the folding pattern. Based upon the recovery positions of the parts of the ruptured anhydrous ammonia tank cars, the cars were likely perpendicular to the track when they were struck broadside by the trailing cars.

During the derailment, the first seven anhydrous ammonia tank cars sustained the greatest and most extensive damage. Five of these tank cars sustained complete catastrophic fracture and separation, instantaneously releasing their entire contents. The other two tank cars received localized shell punctures and released their contents more slowly.

The shells of the five tank cars that catastrophically failed were built before 1989 and were fabricated from non-normalized TC128B steel. Based upon metallurgical examination and testing, the catastrophic fracture of the tank shells from four of the five failed tank cars (GATX 47837, 47982, and 48081 and PLMX 4504) occurred as brittle fractures. The presence of these brittle fractures indicates that the steel shells of these four cars were below the ductile-to-brittle transition temperature, or DBTT, at the time of the derailment, and therefore the fracture toughness[70] of the steel was lower than it would have been had the steel been above the DBTT. For any material, the energy required to propagate cracks in a brittle manner rapidly and over longer distances is much less than that required for ductile crack propagation. Thus, the low impact resistance of the brittle shell material of these four tank cars led to early initiation and rapid, unarrested propagation of cracks. This resulted in the instantaneous release of the anhydrous ammonia and the rocketing of sections of the tank cars.

The fifth car, GATX 47814, also completely fractured and separated. The fractographic examination of this car established that the shell material was ductile at the time of the derailment, and the Charpy testing determined that the DBTT of this material was slightly below -30° F. Ductile fracture and a low DBTT are desirable features, but they must be accompanied by sufficient dynamic fracture toughness. In the case of car GATX 47814, the material was highly anisotropic.[71] Thus, the steel in the shell of this car was vulnerable to low-energy, ductile fracture propagation parallel to the rolling direction

[70] *Fracture toughness* is a measure of the material's ability to resist fracture under static and/or dynamic loading. Unstable fractures are more likely to occur in brittle materials and those with low fracture toughness. Fracture toughness criteria are frequently specified in the design of pressure vessels.

[71] The Safety Board Materials Laboratory report indicates that the energy required to fracture the longitudinal and transverse Charpy specimens for the shell of tank car GATX 47814 was 52 ft-lbs and 18 ft-lbs, respectively.

(circumferential direction in the tank shell) of the plate steel. The ductile fracture for this car was associated with a Charpy energy of 18 ft-lbs. In comparison, two of the brittle fractures were for material with Charpy energy values of 32 and 20 ft-lbs.

To address the problem of brittle and low-energy fracture propagation, the shells of pressure tank cars have, since 1989, been required to be fabricated from normalized steel. Normalizing steel plate has been shown to reduce but not eliminate anisotropy and to significantly reduce the DBTT in comparison to the same steel plate without the normalizing heat treatment. Further, normalizing heat treatment uniformly increases the fracture toughness of the steel plate at all operating temperatures.

Safety Board tests provide clear confirmation of the benefit of normalizing steel. Coupons were machined from the non-normalized shell of GATX 47982. Some of the coupons were subjected to normalizing heat treatment before undergoing Charpy V-notch testing. The energy required to fracture the normalized test coupons at 36° F (the estimated tank shell temperature of the class 105 tank cars at the time of the accident) was approximately 80 percent greater in both orientations (longitudinal and transverse) of testing than that required to fracture the non-normalized test coupons, also at 36° F. Further, the normalized test coupons had a DBTT that was at least 72° F below the DBTT of the non-normalized coupons from the shell of GATX 47982.

Tests performed by the National Institute of Standards and Technology (NIST)[72] in September 1991 demonstrated that with the proper combination of chemistry and processing, normalized TC128B steel can be manufactured with impact resistance energies that are greater by 53 percent (for the transverse specimen) to as much as 135 percent (for the longitudinal specimen) than the corresponding energies obtained in the Safety Board's tests of normalized test coupons from GATX 47982.[73] These improvements are a result of several factors, including smaller ferrite grains and lower amounts of sulfur in comparison with the steel used in the Safety Board experiments.

Therefore, the Safety Board concludes that the low fracture toughness of the non-normalized steels used for the tank shells of the five tank cars that catastrophically failed in this accident contributed to the cars' complete fracture and separation.

However, during the Safety Board's public hearing on this accident, participants representing tank car manufacturers and owners, the AAR, Transport Canada, and the FRA all stated that the pressure tank cars constructed of non-normalized TC128B steel before 1989 were safe and possessed a good safety record. The participants emphasized that catastrophic brittle failures like those seen in the Minot derailment are rare and that they believed that the tank cars would also have failed and released their cargoes of anhydrous ammonia even if the tank car steels had been in a ductile state. However, the

[72] NIST Report No. 24 (NISTIR 4660), "Mechanical Properties and Fracture Toughness of AAR TC128 Grade B Steel in the Normalized, and Normalized and Stress Relieved Conditions," by George E. Hicho and Donald E. Harne.

[73] The amount of the increase in the impact resistance energy depends upon the orientation of the test coupon with respect to the as-rolled direction of the steel plate.

instantaneous release of the 146,700 gallons of anhydrous ammonia within moments of the derailment in Minot produced a much larger and more concentrated plume of ammonia than would have occurred if the same quantity of ammonia were released more slowly, allowing the ammonia to dissipate gradually in the atmosphere.

Further, the complete fracture and fragmentation of tank cars and the rocketing of tank car sections can expose major population centers to serious risks. Consequently, despite the views expressed during the public hearing, the Safety Board is not convinced that these previous research studies provide an adequate safety assessment of pressure tank cars built of non-normalized steel.

Improvement of Tank Car Crashworthiness

Although a normalizing heat treatment improves the impact resistance and reduces the DBTT of a given grade of steel, this treatment alone is not sufficient to ensure that tank cars have adequate impact resistance to eliminate complete shell fractures. 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 or reduce the risk of catastrophic brittle fractures 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. Such an endeavor will require evaluation of the dynamic forces and an integrated analysis of the response of the tank structure, as well as the response of the tank material, to these predicted dynamic loads.

Analysis of the structure must account for stresses generated from internal tank pressures and from dynamic loads applied during impact to any location on the tank and the likelihood that such stresses would be sufficient to initiate and propagate cracks in the tank structure. Computer-aided design and finite element analysis software are used by the tank car industry to address the response of the structure to its operating environment. However, analysis of the steels and their performance in the operating environment have not been integrated into overall tank car design, specifically with respect to the development of improved steels or the establishment of performance standards for currently available steels.

Efforts to model accident forces and develop tank car performance standards should begin concurrently. Certainly, as the modeling of dynamic forces is refined, the development of impact resistance performance standards that have a more accurate and meaningful technical basis will occur.

An improved understanding of the dynamic forces imposed on tank cars under derailment conditions can be realized through the development of predictive models that are validated through comparison with experimental data. The validation must include the influence of stress and temperature in the tank. The validated models can then be used to reliably predict the survivability of tank cars in accident conditions. The FRA, through the

DOT Volpe National Transportation Systems Center, is planning, beginning in fiscal year 2004, to develop a predictive methodology to define the forces acting on tank cars during accidents. This research is expected to take 2 to 3 years to complete. The proposal, however, does not specify how the predictive model will be validated.

Consequently, the Safety Board concludes that the research program proposed by the FRA to model the dynamic forces and evaluate the crashworthiness of tank cars in accident conditions is incomplete without a plan to validate the predictive model. Given the importance of this research, the Safety Board therefore believes that the FRA should validate the predictive model being developed to quantify the maximum dynamic forces acting on railroad tank cars under accident conditions.

The change to the AAR standard requiring that the tank shells of pressure tank cars manufactured after 1988 be constructed of normalized TC128B steel was a significant step to reduce brittle fractures and improve the impact resistance of the steel. However, a normalizing heat treatment does not guarantee a minimum material impact resistance. In order to ensure adequate impact resistance, other factors, such as the chemical composition and grain structure of the metal and the type of rolling process used in the manufacture of the steel, must also be controlled. Thus, the material impact resistance criteria should be based on a material fracture toughness requirement and be performance based for specific tank car designs so that tank car manufacturers may choose the best combination of steel chemical composition, thermal treatment, and rolling processes and fabrication procedures that will satisfy the criteria.

In general, the AAR and the FRA have not established adequate testing standards to measure the impact resistance for steels and other materials used in the construction of pressure tank cars. Several approaches are available for characterizing a material's resistance to dynamic fracture. The Charpy V-notch test is a comparatively simple and inexpensive procedure and is the most commonly used test. Because the Charpy values are dependent on specimen thickness, the standard developed must guarantee that the testing done is consistent with the thickness of the tank car material. To some extent, the AAR and the DOT already require Charpy V-notch tests for certain pressure tank cars. For example, pressure tank cars used in low-temperature service, such as those used to transport specific hazardous materials such as carbon dioxide, vinyl fluoride, and anhydrous hydrogen chloride, must have a minimum average Charpy value of 15 ft-lbs for longitudinal specimens at -50° F. The 15 ft-lb energy required to meet the low temperature standard is below the energy[74] found for samples taken from the non-normalized tank cars that catastrophically fractured in this accident. However, the AAR standards and the DOT Hazardous Materials Regulations (HMR) do not recommend or require Charpy V-notch or other dynamic load testing of steels and metals used in pressure tank cars designed to move the most commonly transported class 2 materials, including anhydrous ammonia and LPG.

[74] Transverse Charpy specimens were tested from three of the accident tank cars, and the average values generated for 36° F were 32, 20, and 18 ft-lbs.

Therefore, the Safety Board concludes that a materials standard to define the minimum level of dynamic fracture toughness, such as a minimum average Charpy value, for the material in all tank cars that transport class 2 hazardous materials, including those in low-temperature service, over the entire range of operating temperatures would provide greater assurance that tank car materials will perform in a safe manner in accident conditions.

Additionally, Charpy V-notch tests performed for the Safety Board Materials Laboratory on specimens from the same tank car but having different directional orientations (relative to the as-rolled direction of the steel) indicated significant differences in impact resistance. In general, longitudinal specimens[75] have greater impact resistance than transverse specimens from the same material. AAR standards and the HMR specify Charpy V-notch testing for TC128B steel for cold-temperature service. These tests are performed using longitudinal specimens (those with the greater impact resistance), rather than transverse specimens. But because the dynamic forces acting on a tank car in an accident develop stresses in all directions, the performance standard for fracture toughness of tank car materials must be determined for the direction with minimum impact-resistant properties.

Because such performance criteria do not exist, the Safety Board believes that the FRA should develop and implement tank car design-specific fracture toughness standards for steels and other materials of construction for pressure tank cars used for the transportation of DOT class 2 hazardous materials, including those in cold-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.

Evaluation of Pre-1989 Pressure Tank Cars

During its public hearing on the Minot accident, the Safety Board explored possible options to reduce the risks posed by pre-1989 pressure tank cars. However, representatives from the FRA and tank car manufacturers raised various objections to each of these options based on concerns about the expense, questionable safety benefits, and new risks that might develop if existing operating procedures were changed for the railroads and shippers.

Neither the FRA nor industry representatives have offered a resolution to the issue of pre-1989 cars other than acknowledging the need to better understand the forces acting on tank cars during derailments and ranking the existing pre-1989 tank car fleet to identify the tank cars with the highest risk. Regarding the ranking of the pre-1989 pressure cars, no specific ideas were offered on how to accomplish such a ranking.

Approximately 60 percent of pressure tank cars currently in service were built before 1989 and very likely were constructed from non-normalized steel. Additionally,

[75] Longitudinal specimens have the length of the specimen oriented parallel to the as-rolled direction of the steel plate.

tank cars may remain in service for up to 50 years, which means that the last pressure tank cars constructed of non-normalized steel could remain in service until 2039. Further, according to AAR statistics, there were more than 1.23 million tank car shipments of hazardous materials in 2000 (the last year for which data are available) in the United States and Canada. Of the top ten hazardous materials transported by tank car, five were class 2 liquefied compressed gases (LPG, anhydrous ammonia, chlorine, propane, and vinyl chloride) that together accounted for more than 246,600 tank car shipments, or about 20 percent of all hazardous materials shipments by tank car.

Consequently, the Safety Board is concerned about the continued transportation of class 2 hazardous materials in pre-1989 tank cars. Because of the high volume of liquefied gases transported in these tank cars and the cars' lengthy service lives, the Safety Board concludes that using these cars to transport DOT class 2 hazardous materials under current operating practices poses an unquantified but real risk to the public.

In order to rank the pre-1989 tank cars, a comprehensive analysis to determine the impact resistance of the steel used for these tank car shells is needed. At a minimum, such an analysis should include data from Charpy V-notch or dynamic fracture toughness tests for the steels found in the pre-1989 pressure tank cars. In the absence of such data, a statistically representative sampling of the shells from pre-1989 tank cars should be tested.

The Safety Board believes that the FRA should conduct a comprehensive analysis to determine the impact resistance of the steels in the shells of pressure tank cars constructed before 1989. At a minimum, the safety analysis should include the results of dynamic fracture toughness tests and/or the results of nondestructive testing techniques that provide information on material ductility and fracture toughness. The data should come from samples of steel from the tank shells from original manufacturing or from a statistically representative sampling of the shells of the pre-1989 pressure tank car fleet. The Safety Board further believes that the FRA should, based on the results of the tank car impact resistance analysis, establish a program to rank pressure tank cars built before 1989 according to their risk of catastrophic fracture and separation, and implement measures to eliminate or mitigate this risk. This ranking should take into consideration operating temperatures, pressures, and maximum train speeds.

Disaster Preparedness

The September 2001 disaster preparedness exercise conducted in Minot covered several possible disaster conditions, including damaged railcars leaking hazardous material. The exercise not only tested and evaluated emergency operations plans and response preparedness, it also assessed the performance of response organizations during hazardous materials releases, personal injuries, and evacuations. The broad scenario of this exercise also provided an opportunity for the various Federal, State, and local organizations to work together during an emergency. Therefore, the Safety Board concludes that before the accident the Minot emergency responders, the city of Minot, and the CPR had conducted a disaster preparedness exercise that enhanced the effectiveness of the emergency response to the anhydrous ammonia release on January 18, 2002.

Emergency Response

Minot Rural Fire Department

After the Minot Rural Fire Department was notified of the accident immediately following the derailment, the chief of the department began to call for mutual assistance from nearby fire departments. The chief arrived on-scene within 10 minutes of the accident. Upon his arrival, he assumed incident command and set up a field command post. The chief immediately determined that the leaking material was anhydrous ammonia because he was familiar with the smell of the chemical. Within an hour of the accident, the chief recognized the magnitude of the incident and decided to open an emergency operations center. Because the cloud of anhydrous ammonia was heading toward the downtown area and the location of the designated emergency operations center, the chief requested the use of Minot City Fire Station Number 1, which was not specified as an emergency operations center.

Further, because of the large amount of anhydrous ammonia released, the atmosphere around the Tierracita Vallejo neighborhood was not deemed safe for emergency responders until approximately 3 hours after the accident. Therefore, the chief appropriately kept emergency responders from entering the accident area until the area was deemed safe so as not to put more persons at risk from the effects of the anhydrous ammonia. However, as soon as they could, emergency responders entered the neighborhood and went door-to-door to provide medical treatment and evacuate the residents.

Trinity Hospital

Because Trinity Hospital had been an active participant in disaster drills with local emergency responders and was prepared to handle a hazardous materials disaster, hospital staff were able to treat more than 300 persons in a timely and efficient manner.

Ward County 911

Throughout the period in which the anhydrous ammonia plume affected the Minot area, Ward County 911 dispatchers answered more than 2,800 telephone calls concerning this accident. These dispatchers typically answer an average of 36 emergency calls a day. During the response to this accident, the dispatchers answered more than 77 times as many calls.

From the first call and throughout the course of the emergency response, the Ward County 911 dispatchers told callers to stay in their homes, close their windows, and stay calm. The 911 operators also provided callers with the following correct guidance on dealing with anhydrous ammonia:

> … stay in their homes and shut down their furnaces and air handling systems, go into their bathroom and use large amounts of water—turn on their shower and breathe through a wet cloth.

Even with a higher than usual number of emergency phone calls to handle, the Ward County 911 dispatchers continued to respond to incoming calls and give callers correct information on how to respond to the anhydrous ammonia emergency. Therefore, the Safety Board concludes that the Ward County 911 dispatchers provided accurate and timely information to the residents of Minot even though the system received more than 2,800 calls immediately after the accident.

Notifications to the Public

After the accident, the Minot Police Department made emergency notifications to the public that included cable television interrupts, radio broadcasts, and outdoor warning sirens. However, because many homes in Minot lost power when derailed cars knocked over power lines next to the railroad tracks, many residents did not hear the emergency guidance on radio and cable television. Additionally, persons in the houses in Tierracita Vallejo did not hear the outdoor warning sirens because the neighborhood is outside the city of Minot.

Since the accident, the Minot Police Department has made a number of changes to the ways in which it contacts outlets for emergency broadcasts on both radio and television. Now Minot Central Dispatch has the phone numbers of key media staff of all Minot area stations and can contact them when necessary.

Survival Factors

Fatal Injury

In an attempt to escape the anhydrous ammonia fog, shortly after the derailment a 38-year-old male resident of the Tierracita Vallejo neighborhood, with his wife as a passenger, drove his pickup truck into the cloud. In the toxic cloud, he lost control of the pickup truck, and it collided with the side of a house across the street. The man and his wife then attempted to flee on foot, but although the wife was able to get inside a neighbor’s home, the husband collapsed and died in the driveway. According to the Ward County Coroner, the cause of death was prolonged exposure to anhydrous ammonia.

Against the broadcast guideline to shelter in place (although it is unknown whether the man or his wife had heard or seen an emergency broadcast), the man and his wife left the protection of their home. Once they were outside, they were in the toxic cloud with no protection from it. Because access to the area affected by the vapor cloud was restricted so as not to endanger the emergency responders, the man who collapsed and died was not removed by emergency responders until approximately 5:15 a.m.

Survivor Injuries

Operating Crew. The conductor likely sustained his injuries when he exited the locomotive, evaluated the situation, and walked back to disconnect the locomotives from the rest of the train. To disconnect the locomotives, he had to walk directly through the anhydrous ammonia cloud. Although this direct exposure to the ammonia caused his injuries, the severity of those injuries was limited by his leaving the area immediately thereafter.

The engineer stayed inside the locomotive compartment so he was somewhat protected from the effects of the anhydrous ammonia and only received minor injuries. In addition, he also left the area quickly, which limited his exposure to the anhydrous ammonia.

Emergency Responders. The six Minot Rural Fire Department firefighters who sustained minor injuries (headaches, sore throats, eye irritation, and/or chest pain) were all equipped with and required by the Minot Rural Fire Department standard operating procedure to use an SCBA. However, the firefighters attempting the initial rescue into the Tierracita Vallejo neighborhood were not using their SCBAs, and they sustained minor injuries consistent with exposure to anhydrous ammonia. The chief of the Minot Rural Fire Department told Safety Board investigators that since the accident, he has met with Minot Rural Fire Department firefighters and re-emphasized the importance of using SCBAs. He also has reviewed the SCBA standard operating procedure with the firefighters.

The 11 Minot police officers who sustained minor injuries (eye irritation, chest discomfort, respiratory distress, and/or headaches) likely were exposed to anhydrous ammonia at times while blocking and directing traffic around the perimeter of the accident. Their exposure was limited, and they prevented countless Minot residents from entering the anhydrous ammonia cloud.

The Ward County Sheriff's Department officer who became disoriented and drove his car into a ditch stayed inside his vehicle for about 45 minutes until he was rescued. The severity of his exposure to the anhydrous ammonia was limited because he remained in his vehicle with the windows closed and the heater off.

Residents. The Tierracita Vallejo neighborhood of approximately 22 homes is bordered by the railroad tracks, a river, and a highway, which is the only road into and out of the neighborhood. Because of the proximity of the derailment to the neighborhood, a high concentration of anhydrous ammonia settled in the neighborhood, leading the chief of the Minot Rural Fire Department to prohibit emergency responders from entering the neighborhood. The neighborhood was effectively sealed off from the rest of the city by the combination of the toxic cloud, which prevented entry by emergency responders and exit by residents, and the law enforcement personnel who prohibited entry into the neighborhood.

At least three residents of the Tierracita Vallejo neighborhood sustained serious injuries as a result of the accident. All of these persons left the protective confines of their homes and were directly exposed to the anhydrous ammonia cloud for a prolonged period of time, resulting in their serious injuries. The cloud of anhydrous ammonia was fog-like and very thick, with witnesses reporting almost no visibility through the cloud. Once the persons were inside the anhydrous ammonia cloud, the poor visibility disoriented them and contributed to their prolonged exposure to the anhydrous ammonia.

Eight residents of other parts of Minot sustained serious injuries as a result of exposure to anhydrous ammonia. The medical records of these residents indicated pre-existing health problems, such as asthma and heart conditions, that likely exacerbated the effects of ammonia exposure.

The number of residents who sustained injuries as a result of the accident was quite low in comparison to the estimated number who were exposed to the anhydrous ammonia cloud: 312 injuries in 11,600 persons affected. The residents who sustained serious injuries were those who were directly exposed to anhydrous ammonia because they left the protection of their homes and vehicles or who had pre-existing health problems that exacerbated the effects of the ammonia exposure.

Shelter-In-Place

Early in the emergency response, the chief of the Minot Rural Fire Department decided that the best thing the residents of Minot could do to protect themselves from the anhydrous ammonia was to stay in their homes, called sheltering-in-place. This response to an emergency is different from an evacuation because the people who shelter-in-place stay in the hot zone, whereas in an evacuation, the affected people leave the hot zone. The chief notified the Ward County 911 center and the local media of the shelter-in-place decision in a timely manner.

For the first few hours after the accident, the residents of Tierracita Vallejo were effectively trapped in their homes. Because of the nature of anhydrous ammonia, however, being trapped in their homes was actually the best possible situation for those so close to the derailment. However, because none of these homes had power and since only a few residents received updates either from battery-powered radios or from phone conversations with people elsewhere in Minot, after a few hours these residents felt abandoned by the emergency responders. Since the accident, the Minot Rural Fire Department has met with these residents to explain its emergency response to the accident.

Safety Board investigators researched shelter-in-place guidelines set forth in the 2000 Emergency Response Guidebook[76] and in National Fire Protection Association[77] Standard 472.[78] These guides assert the importance of sheltering residents in their homes when evacuating them could cause greater risk due to the amount and direction of travel of the hazardous material. The chief consulted both of these guides and used them to establish the shelter-in-place order. Therefore, the Safety Board concludes that the decision by the chief of the Minot Rural Fire Department to shelter the residents of Minot in their homes during the anhydrous ammonia release represented an effective response to the emergency.

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[76] U.S. Department of Transportation, Research and Special Programs Administration, *Emergency Response Guidebook, 2000: A Guidebook for First Responders During the Initial Phase of a Dangerous Goods/Hazardous Materials Incident* (Washington, D.C.: 2000).

[77] The National Fire Protection Association provides fire, electrical, and life safety information to the general public. Its membership numbers more than 75,000 worldwide and more than 80 national trade and professional organizations. Its mission is to reduce the effects of fire and other hazards on the quality of life by advocating and providing scientifically based consensus codes and standards, research, training, and education.

[78] National Fire Protection Association, *Standard for Professional Competence of Responders to Hazardous Materials Incidents* (1997), NFPA, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.

Conclusions

Findings

1. Train crew qualifications and train operations were not factors in this accident, and there was no evidence found that crew fatigue or alcohol or drug use were causal or contributory to the accident.

2. The derailment was not caused by a mechanical or component failure of any of the train's rolling stock.

3. The joint bars at the east end of the plug rail fractured under the previous train or as the accident train passed over the joint, and after the joint bars fractured, the rail itself also fractured and broke away, causing train 292-16 to derail.

4. Canadian Pacific Railway inspection procedures before the accident were inadequate to properly inspect and maintain joints within continuous welded rail, and those inadequate procedures allowed undetected cracking in the joint bars at the accident location to grow to a critical size.

5. Federal Railroad Administration requirements regarding rail joint bars in continuous welded rail are ineffective because they do not require on-the-ground visual inspections or nondestructive testing adequate to identify cracks before they grow to critical size and result in joint bar failure.

6. Canadian Pacific Railway's track procedure manual was confusing and thus did not provide employees with clear guidance on the practices to be followed in installing and maintaining continuous welded rail.

7. The Federal Railroad Administration's oversight of the Canadian Pacific Railway's continuous welded rail program was ineffective because the agency neither reviewed the program nor ensured that its track inspectors had copies of the program to determine if the railroad was in compliance with it.

8. The catastrophic fracture of five tank cars increased the severity of the accident by exposing residents to high concentrations of toxic vapors from the instantaneous release of 146,700 gallons of anhydrous ammonia and to the rocketing of portions of tank cars.

9. The low fracture toughness of the non-normalized steels used for the tank shells of the five tank cars that catastrophically failed in this accident contributed to the cars' complete fracture and separation.

10. Using tank cars built before 1989 and fabricated from non-normalized steel to transport U.S. Department of Transportation class 2 hazardous materials under current operating practices poses an unquantified but real risk to the public.

11. The research program proposed by the Federal Railroad Administration to model the dynamic forces and evaluate the crashworthiness of tank cars in accident conditions is incomplete without a plan to validate the predictive model.

12. A materials standard to define the minimum level of dynamic fracture toughness for the material in all tank cars that transport class 2 hazardous materials over the entire range of operating temperatures would provide greater assurance that the tank car materials will perform in a safe manner in accident conditions.

13. Before the accident, the Minot emergency responders, the city of Minot and the Canadian Pacific Railway had conducted a disaster preparedness exercise that enhanced the effectiveness of the emergency response to the anhydrous ammonia release on January 18, 2002.

14. The Ward County 911 dispatchers provided accurate and timely information to the residents of Minot even though the Ward County 911 system received more than 2,800 calls immediately following the accident.

15. The decision by the chief of the Minot Rural Fire Department to shelter the residents of Minot in their homes during the anhydrous ammonia release represented an effective response to the emergency.

Probable Cause

The National Transportation Safety Board determines that the probable cause of the derailment of Canadian Pacific Railway train 292-16 was an ineffective Canadian Pacific Railway inspection and maintenance program that did not identify and replace cracked joint bars before they completely fractured and led to the breaking of the rail at the joint. Contributing to the severity of the accident was the catastrophic failure of five tank cars and the instantaneous release of about 146,700 gallons of anhydrous ammonia.

Recommendations

As a result of its investigation of the January 18, 2002, freight train derailment near Minot, North Dakota, the National Transportation Safety Board makes the following safety recommendations:

To the Federal Railroad Administration:

> Require all railroads with continuous welded rail track to include procedures (in the programs that are filed with the Federal Railroad Administration) that prescribe on-the-ground visual inspections and nondestructive testing techniques for identifying cracks in rail joint bars before they grow to critical size. (R-04-1)
>
> Establish a program to periodically review continuous welded rail joint bar inspection data from railroads and Federal Railroad Administration track inspectors and, when determined necessary, require railroads to increase the frequency or improve the methods of inspection of joint bars in continuous welded rail. (R-04-2)
>
> Instruct Federal Railroad Administration track inspectors to obtain copies of the most recent continuous welded rail programs of the railroads that fall within the inspectors' areas of responsibility and require that inspectors use those programs when conducting track inspections. (R-04-3)
>
> Conduct a comprehensive analysis to determine the impact resistance of the steels in the shells of pressure tank cars constructed before 1989. At a minimum, the safety analysis should include the results of dynamic fracture toughness tests and/or the results of nondestructive testing techniques that provide information on material ductility and fracture toughness. The data should come from samples of steel from the tank shells from original manufacturing or from a statistically representative sampling of the shells of the pre-1989 pressure tank car fleet. (R-04-4)
>
> Based on the results of the Federal Railroad Administration's comprehensive analysis to determine the impact resistance of the steels in the shells of pressure tank cars constructed before 1989, as addressed in Safety Recommendation R-04-4, establish a program to rank those cars according to their risk of catastrophic fracture and separation and implement measures to eliminate or mitigate this risk. This ranking should take into consideration operating temperatures, pressures, and maximum train speeds. (R-04-5)

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-04-6)

Develop and implement tank car design-specific fracture toughness standards, such as a minimum average Charpy value, for steels and other materials of construction for pressure tank cars used for the transportation of U.S. Department of Transportation class 2 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. (R-04-7)

To the Canadian Pacific Railway:

Finalize and submit to the Federal Railroad Administration your revised continuous welded rail maintenance program and ensure that all maintenance employees are trained in the requirements of the new program. (R-04-8)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

Ellen Engleman Conners
Chairman

Mark V. Rosenker
Vice Chairman

Carol J. Carmody
Member

Richard F. Healing
Member

Adopted: March 9, 2004

Member John J. Goglia did not participate in the adoption of this report.

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Appendix A

Investigation and Public Hearing

The National Transportation Safety Board was notified of the Minot, North Dakota, accident during the morning of January 18, 2002. An investigative team was dispatched with members from the Washington, D.C.; Chicago, Illinois; and Los Angeles, California, offices. The following investigative groups were established: railroad operations, track, mechanical, hazardous materials, and emergency response/survival factors.

On scene participating in the investigation were representatives of the Federal Railroad Administration, the Canadian Pacific Railway, the Minot Rural Fire Department, the United Transportation Union, and the Brotherhood of Locomotive Engineers.

Public Hearing

A public hearing was held in Washington, D.C., on July 15 and 16, 2002. The chairman of the board of inquiry was then-Vice Chairman Carol Carmody.

The following were designated as parties to the hearing in accordance with Part 845.13 of the Safety Board's procedural regulations:

Canadian Pacific Railway

Federal Railroad Administration

City of Minot

Trinity Industries, Inc.

General American Transportation Corporation

Association of American Railroads Tank Car Committee

Brotherhood of Maintenance-of-Way Employees

Appendix B

Minot Accident Timeline

The following events occurred on January 18, 2002, unless otherwise noted.

0137	First call into Ward County 911 reporting derailment. This call from the train conductor reports an explosion near Tierracita Vallejo on Canadian Pacific Railway with hazardous material. Emergency responders are paged to respond.
0140	The chief and an assistant chief of the Minot Rural Fire Department acknowledge the page
0141	Residents of 625 37th Street SW call 911 reporting bad smell and that their 12-year-old daughter had gone outside. The 911 operator tells the residents to stay put because it is worse outside.
0143	Resident of Tierracita Vallejo calls 911. The 911 operator tells them to stay calm and stay in the house and that, if necessary, evacuations will be announced. The 911 operator also tells them to close all windows.
0144	The Minot Rural Fire Department requests mutual aid from the Minot City Fire Department and Burlington Fire Department.
0147	The Canadian Pacific Railway crew approaches the Arrowhead grade crossing (at 16th Street and approximately 2nd Avenue SW) and come upon a Minot Fire Department battalion chief waiting at the crossing.
0147	The Minot Rural Fire Department chief arrives on scene at the West 83 Bypass at the intersection of 4th Avenue NW (approximately 1/2 mile east and 1/2 mile north of the train derailment site). He immediately assumes incident command and performs an initial site and accident assessment.
0149	The Minot Air Force Base Hazardous Materials Team is notified of the accident.
0150	The Minot Rural Fire Department chief establishes a field incident command post along the West 83 Bypass near the intersection of 19th Avenue NW.
0150	The emergency room at Trinity Hospital is notified of the derailment.
0150	The Canadian Pacific Railway train dispatcher informs Ward County 911 of an anhydrous ammonia train derailment and suggests looking at evacuation procedures.
0151	The Minot Rural Fire Department chief reports that a cloud of anhydrous ammonia is heading over Minot. The chief states that the anhydrous vapor cloud is traveling in an east/northeast direction.
0154	Minot fire command reports an extremely heavy vapor cloud on the bypass by the neighborhood nearest the derailment and requests to shut the roads down.
0158	The Minot Rural Fire Department notifies Community Ambulance of an anhydrous ammonia release.

0206	A female resident of 601 36th Street reports a man down outside her house. She states that his wife has just come into the house. The man is 37 years old. The 911 operator says that people are in the area and that they have to take precautions but can't give a time right now.
0209	An initial staging area is set up at the West 83 Bypass near 21st Avenue NW. Responding units are directed to travel around the city of Minot to reach the north side of the incident.
0213	The Minot Rural Fire Department requests that the Burlington Fire Department meet the Minot firefighters at Behm's Truck Stop just west of the 83 Bypass along Highway 2 and 52 (southwest of the derailment location).
0223	Des Lacs and Berthold Fire Departments are paged out by State Radio for mutual aid assistance.
0225	Trinity Hospital activates its disaster plan ("Code Green").
0230	Burlington First Responders establish a triage/treatment center at Baptist Church on the western edge of Burlington, a community approximately 6 miles northwest of the accident location, in order to treat any displaced persons should they head to Burlington.
0237	The emergency operations center is opened at Minot City Fire Station Number 1. At this time, Minot Rural Fire Department engine 214 is assigned as the mobile command unit, a Minot Rural Fire Department assistant chief is assigned as the on-scene incident commander, and the Minot Rural Fire Department chief maintains command at the emergency operations center.
0237	The Ward County disaster plan is activated.
0238	A cable interrupt is issued, the outdoor warning system is activated, and a public address announcement is put out to radio stations. The announcements inform the residents of Minot to shelter in their homes, shut down their furnaces and air handling systems, and if necessary, use large amounts of water from their shower and breathe through wet wash cloths.
0240	Minot Rural Fire Department engines 214 and 216 stage at 21st Avenue NW, and Minot Rural Fire Department unit 218 reports that all the civilians are inside at Behm's Truck Stop.
0242	The vapor cloud is reported to completely cover the Highway 2/52/83 Bypass.
0242	The cable interrupt is given again.
0243	The mobile command post is repositioned upon a hill at the landfill.
0245	A decision is made to evacuate the people at Behm's Truck Stop
0300	Edison Elementary School is opened as a shelter.
0309	The cable interrupt is done a third time
0335	Television station KXMC is contacted to scroll a message for people to stay in their homes and take appropriate action.
0412	Trinity Hospital reports that the anhydrous vapor cloud is directly over the hospital.

0415	A triage team from Trinity Hospital consisting of three physicians, eight nurses, and two respiratory therapists respond to Edison Elementary School.
0429	The Minot Rural Fire Department relocates the staging area for rescue operations to the Behm's Truck Stop on Highway 2 & 52, just west of the West 83 Bypass.
0430	The emergency operations center requests mutual aid from the Minot Air Force Base ambulances. Three ambulances with two medics per unit respond along with one physician from the Minot Air Force Base Health Clinic.
0439	A resident of Tierracita Vallejo (601 36th Street SW) calls to report that a woman in the house is in very bad shape because she was out in the cloud. He says that there is no vapor cloud and is wondering when responders will be there. He says the woman's husband is still outside.
0447	Minot Rural Fire Department unit 219 goes into the Tierracita Vallejo neighborhood to rescue the residents. This first unit comes upon the 37-year-old male victim outside 601 36th Street SW. The firefighters exit their unit without their SCBAs (self-contained breathing apparatus) in an attempt to recover the victim. They are unable to recover the victim and have to depart the scene and regroup at the staging area. Another attempt is made by firefighters, but this time all rescuers are wearing "structural" personal protective equipment (bunker gear) and wearing SCBAs.
0504	Minot Airport manager reports that the airport is closed except for emergency traffic.
0821	After a secondary check of all the houses to ensure that no one is left behind, the rescue operation of the Tierracita Vallejo neighborhood is complete. The chief estimates that approximately 60 to 65 residents of the Tierracita Vallejo neighborhood were rescued.
1230	Trinity Hospital deactivates the Code Green.
1307	The shelter and triage area at Edison Elementary School is closed.
1400	The Minot Rural Fire Department closes the field command post.
January 20, 2002, 1000	The Minot Rural Fire Department chief relocates the emergency operations center to the Minot Municipal Auditorium.
March 11, 2002	The residents of the Tierracita Vallejo neighborhood are allowed to return to their homes.
March 19, 2002	The emergency operations center is closed.

Appendix C

Train 292-16 Consist

Car #	ID Number	Contents
1	SOO 75751	Urea
2	SOO 75116	Urea
3	NAHX 467085	Urea
4	SOO 73223	Urea
5	NAHX 801236	Urea
6	NAHX 29646	Empty
7	WW 3008	Empty
8	CRDX 9259	Empty
9	WW 3185	Empty
10	UP77444	Empty
11	ACFX 60256	"POLELASTBLACKS"
12	ACFX 47138	"SOUTHWIRBLACKS"
13	SOO 74465	Urea
14	SOO 116692	Urea
15	SOO 117986	Urea
16	SOO 117060	Urea
17	SOO 115944	Urea
18	PLMX 4644	Anhydrous Ammonia, 2.4, UN 1005
19	GATX 47814	Anhydrous Ammonia, 2.4, UN 1005
20	GATX 47837	Anhydrous Ammonia, 2.4, UN 1005
21	GATX 49248	Anhydrous Ammonia, 2.4, UN 1005
22	GATX 47982	Anhydrous Ammonia, 2.4, UN 1005
23	GATX 48081	Anhydrous Ammonia, 2.4, UN 1005
24	PLMX 4504	Anhydrous Ammonia, 2.4, UN 1005
25	GATX 58659	Anhydrous Ammonia, 2.4, UN 1005
26	GATX 49285	Anhydrous Ammonia, 2.4, UN 1005
27	GATX 58718	Anhydrous Ammonia, 2.4, UN 1005

Car #	ID Number	Contents
28	GATX 48004	Anhydrous Ammonia, 2.4, UN 1005
29	GATX 48529	Anhydrous Ammonia, 2.4, UN 1005
30	GATX 47822	Anhydrous Ammonia, 2.4, UN 1005
31	GATX 48103	Anhydrous Ammonia, 2.4, UN 1005
32	NATX 35798	Anhydrous Ammonia, 2.4, UN 1005
33	CP 319013	Lumber
34	SGLR 6160	Lumber
35	SGLR 6104	Lumber
36	SGLR 6105	Lumber
37	CP 319137	Lumber
38	TTZX 864036	Lumber
39	SGLR 6184	Lumber
40	CTRN 501349	Empty
41	SGLR 6095	Empty
42	SGLR 6145	Lumber
43	NCLX 66	Polyethylene
44	TILX 400176	Liquefied Petroleum Gas, 2.1, UN 1075
45	TILX 400514	Liquefied Petroleum Gas, 2.1, UN 1075
46	PLMX 20360	Liquefied Petroleum Gas, 2.1, UN 1075
47	PLMX 20404	Liquefied Petroleum Gas, 2.1, UN 1075
48	PLMX20432	Liquefied Petroleum Gas, 2.1, UN 1075
49	EOGX 4137	Glycol
50	EOGX 4157	Glycol
51	EOGX 4124	Glycol
52	EOGX 4139	Glycol
53	AOUX 5090	Glycol
54	AOUX 5097	Glycol
55	AOUX 5006	Glycol
56	EOGX 4097	Glycol
57	EOGX 4102	Glycol
58	AOUX 5103	Glycol
59	EOGX 4056	Glycol
60	EOGX 4153	Glycol

Car #	ID Number	Contents
61	AOUX 5081	Glycol
62	AOUX 5009	Glycol
63	AOUX 5052	Glycol
64	EOGX 4120	Glycol
65	EOGX 4047	Glycol
66	AOUX 5085	Glycol
67	AOUX 5033	Glycol
68	EOGX 4125	Glycol
69	EOGX 4141	Glycol
70	EOGX 4073	Glycol
71	AOUX 5080	Glycol
72	SGLR 6005	Lumber
73	CGTX 26337	Styrene Monomer, Inhibited, 3 UN 2055
74	PROX 23173	Styrene Monomer, Inhibited, 3 UN 2055
75	CGTX 26345	Styrene Monomer, Inhibited, 3 UN 2055
76	CGTX 26255	Styrene Monomer, Inhibited, 3 UN 2055
77	CGTX 26243	Styrene Monomer, Inhibited, 3 UN 2055
78	CGTX 26331	Styrene Monomer, Inhibited, 3 UN 2055
79	PROX 23242	Styrene Monomer, Inhibited, 3 UN 2055
80	CGTX 26245	Styrene Monomer, Inhibited, 3 UN 2055
81	CGTX 26150	Styrene Monomer, Inhibited, 3 UN 2055
82	CGTX 26211	Styrene Monomer, Inhibited, 3 UN 2055
83	CHVX 197029	Residue-Last Contained Hydrocarbons, Liquid NOS, 3, UN 3295
84	PROX 23161	Styrene Monomer, Inhibited, 3 UN 2055
85	TTGX 996685	Empty
86	CSXT 130037	Empty
87	CSXT 502692	Empty
88	CSXT 137456	Empty
89	TNMR 12004	Lumber
90	CP 318229	Lumber
91	TTGX 159230	Empty
92	TTGX 930177	Empty
93	TTGX 992315	Empty

Car #	ID Number	Contents
94	TTGX 982613	Empty
95	NAHX 490302	Empty
96	TLCX 31094	Empty
97	NAHX 56747	Empty
98	TEIX 33594	Liquefied Petroleum Gas, 2.1, UN 1075
99	GATX 61011	Residue-Last Contained Fluosilicic Acid, 8, UN 1778
100	UTLX 646193	Residue-Last Contained Petroleum Distillates, Combustible, UN 1268
101	CP 214109	Wood Pulp
102	ATW 40045	Wood Pulp
103	ACFX 18671	Liquefied Petroleum Gas, 2.1, UN 1075
104	MAPX 12009	Liquefied Petroleum Gas, 2.1, UN 1075
105	ARPX 5101	Liquefied Petroleum Gas, 2.1, UN 1075
106	PLMX 3491	Liquefied Petroleum Gas, 2.1, UN 1075
107	INFX 408199	Empty
108	CNW 169131	Empty
109	ACFX 68470	Empty
110	SSW 87609	Empty
111	MP 643058	Empty
112	MP 650221	Empty

Appendix D

Emergency Response

The following 13 fire departments responded to the anhydrous ammonia release emergency:

Agency	# of Firefighters	# of Units
Minot Rural Fire Department	20	8
Berthold Fire Department	4	2
Burlington Fire Department	22	4
Carpio Fire Department	1	1
Des Lacs Fire Department	15	3
Douglas Fire Department	8	1
Glenburn Fire Department	5	2
Minot Air Force Base Fire Department	17	3
Minot Fire Department	10	5
Mohall Fire Department	6	2
Ryder/Makoti Fire Department	5	3
Surrey Fire Department	5	0
Velva Fire Department	4	2

The following 32 agencies were either represented or had a presence at the emergency operations center:

Minot Rural Fire Department
Minot Fire Department
Minot Air Force Base Fire Department
Minot Police Department
Ward County Sheriff's Office
North Dakota Highway Patrol
Ward County Emergency Management
City of Minot Pubic Works
Environmental Protection Agency – Denver Field Office
North Dakota State Health Department
1st District Health Unit – Minot
Trinity Hospital
Canadian Pacific Railway
North Dakota Veterinarian's Office
North Dakota Governor's Office
North Dakota Department of Emergency Management
North Dakota National Guard
United States Air Force – 55th Civil Support Team
Federal Railroad Administration
Federal Bureau of Investigation
National Weather Service
United States Department of Health and Human Services – Bismarck, North Dakota
Wenck Associates, Inc. – Maple Plain, Minnesota
URS Operating Services, Inc. – Denver, Colorado
Burress Advisory Group – Omaha, Nebraska
Minot Recreation Office
Xcel Energy – Minot
Red Cross – Minot
Civil Air Patrol – Minot
Voluntary Organizations Active in Disasters – Minot
Radio Amateur Civil Emergency Service – Minot
Salvation Army

Appendix E

Charpy V-Notch Testing and DBTT

A method for determining the brittleness of steel is Charpy V-notch impact testing. In Charpy testing, a falling pendulum strikes a rectangular specimen. The specimen has a V-shaped notch[79] in the middle and is supported at each end. The test measures the amount of energy (typically in ft-lbs) that is required to fracture a specimen.

A plot of impact energy versus temperature shows graphically how the material makes a transition from ductile to brittle behavior with decrease in temperature. This plot, called a transition temperature curve, does not show the ductile-to-brittle transition temperature (DBTT) directly, but the DBTT can be derived from the constructed curve. The curve will typically have an upper and lower "shelf" where the fracture energy remains nearly constant relative to the temperature. The temperature associated with the average of the energies of the upper and lower shelves is defined as the DBTT.

In very broad terms, materials that fracture above the DBTT are ductile, and materials that fracture below the DBTT are brittle. Material specification standards can specify that Charpy specimens fracture at specific temperatures with a minimum amount of energy. The presence of brittle fracture features on a broken Charpy V-notch specimen indicates that the specimen was exposed to a temperature below the DBTT and fractured at low amounts of energy during the fracture process.

AAR M-1002 for TC128B steel specifies that Charpy V-notch testing is performed only when a tank car is manufactured for low-temperature service. Although the AAR specification does not define low-temperature service, the term typically is applied to tank cars that transport products such as carbon dioxide, vinyl fluoride, and hydrogen chloride that are loaded at temperatures below -20° F. AAR M-1002 requires that TC128B steel for low-temperature service be furnished in the normalized condition. AAR M-1002 also requires that Charpy testing of the material be performed at -50° F, and that the average energy required to break three specimens at this temperature is a minimum of 15 ft-lbs with no one specimen breaking below a minimum of 10 ft-lbs. The testing is to be performed with longitudinal specimens (length of the specimen oriented parallel to the direction of rolling) in accordance with ASTM 370.

[79] The notch serves to concentrate the stress on the metal, ensuring that fracture will occur at that location.

Appendix F

Tank Car Damage

Tank Car Position – ID #	Detailed Damage Descriptions
18 – PLMX 4644	Easternmost tank car in the derailment. Car on its side with B end facing south. Mainly sidewall damage near A end with complete product loss. Tank shell torn in the A-right side quadrant from near the top of the tank to the bottom centerline. Tear in A-right side of shell extended from top half to nearly the bottom center line. Bolster/coupler assembly undamaged on B end and has slug of product (approximately 200 gal.) in lower portion of B end.
19 – GATX 47814	Separated into two sections about midway between the dome and the B end. The A end was found approximately 120 feet north of the tracks and the B end was approximately 50 feet south of the tracks.
20 - GATX 47837	Top third of the A end tank head missing. Main body of the tank was found along the creek on the south side of the tracks, approximately 200 feet from the tracks. Manway facing north and section of the A end head missing. The top of the tank car was flattened.
21 – GATX 49248	Located on its side, approximately 50 feet on the south side of tracks with its protective housing beside GATX 58639. Has a 12- to 14-inch puncture hole in B-right side of tank. Several hundred of gallons of product remain.
22 – GATX 47982	Separated into at least two sections. Circumferential separation in shell was between A end and dome. One end was propelled approximately 1,200 feet southeast and struck a residence. Shell collapsed to less than 6 feet minimum diameter.
23 – GATX 48081	Separated into at least two sections. Circumferential separation in shell about 1/3 back from the B end toward the dome. The B end was ejected 150 feet northeast.
24 – PLMX 4504	Separated into at least two sections. Circumferential separation in shell was about 1/3 back from the A end toward the dome. B end projected about 50 feet north; protective housing sheared off.
25 – GATX 58659	Car on its side with dome facing east. Considered to be full. Small leak from fitting, valve or connection on the manway. Dents in A end jacket and tank head; jacket damaged bottom center.
26 – GATX 49285	Found on its side with dome fittings leaking. No visible damage to tank. A and B end stub sills torn off.
27 – GATX 58718	Good condition; product at 55 psig. Found on its side with dome facing south on the north side of the tracks. Damage to jacket on B end left and B end right quadrants and B end head.
28 – GATX 48004	Car on its side with its protective housing against GATX 58659. Vapor leaking from the dome housing. A end stub sill is missing.
29 – GATX 48529	Car on its side parallel to the tracks on its side. Considered to be full. Jacket damaged along the left side and in AR quadrant. B end stub sill torn off.
30 – GATX 47822	Car on its on side parallel to the tracks on its side. Considered to be full. Damage undetermined.
31 – GATX 48103	Auto-refrigerated at 0 psig internal pressure. Frost marking indicates tank is more than 50% full. Possible internal crack but location is not apparent. Jackets for A and B end heads damaged.
32 – NATX 35798	Westernmost tank car, appears to be in good condition. There are no apparent leaks and it appears to be full. Jacket damaged along the right side and bottom.