National Transportation Safety Board
Washington, D.C. 20594

Safety Recommendation

Date: March 15, 2004

In reply refer to: R-04-1 through -7

Honorable Allan Rutter
Administrator
Federal Railroad Administration
1120 Vermont Avenue, N.W.
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At approximately 1:37 a.m. 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. 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.[1]

The National Transportation Safety Board determined that the probable cause of the derailment of CPR train 292-16 was an ineffective CPR 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 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.

The main track in the subdivision in which the accident occurred (the Portal Subdivision) was continuous welded rail (CWR); however, the CWR had numerous joints where defective

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

sections of rail had been cut out and replaced with pieces of matching rail called “plugs.” 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 a 36-foot plug in the north rail that was inserted with 36-inch joint bars. The joint on the west end of the plug 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 concluded 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.

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 concluded 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.

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 concluded 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, in their CWR maintenance programs, procedures that prescribe on-the-ground visual inspections and nondestructive testing techniques that will identify 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 necessary, require railroads to increase the frequency or improve the methods of inspections of joint bars in CWR.

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

Consequently, no comparison could be made between the program standards and actual conditions, and 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 concluded that the FRA'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. The Safety Board believes that the FRA should instruct its track inspectors to acquire the most recent CWR programs of the railroads that fall within the inspectors' areas of responsibility and should require that inspectors use those programs when conducting track inspections.

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. Based upon metallurgical examination and testing, the catastrophic fracture of the tank shells from four of the five failed tank cars 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[2] 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 tank of the fifth car that catastrophically failed was ductile at the time of the derailment (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. Safety Board tests determined that the steel in the shell of this car was vulnerable to low-energy, ductile fracture propagation parallel to the rolling direction (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; that is, steel that has been subjected to a specific heat treatment procedure. Normalizing steel plate has been shown 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. The shells of the five tank cars that catastrophically failed were built before 1989 and were fabricated from non-normalized TC128B steel.

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[2] *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.

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.

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, 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 Association of American Railroads (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 concluded that using these cars to transport U.S. Department of Transportation (DOT) class 2 hazardous materials under current operating practices poses an unquantified but real risk to the public.

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. 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.

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 FRA, through the DOT Volpe National Transportation Systems Center, is planning, beginning in FY 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.

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. Consequently, the Safety Board concluded 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 requirement that 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 processes 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 process 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[3] 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 liquefied petroleum gas.

Therefore, the Safety Board concluded 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[4] have greater impact resistance than transverse specimens from the same material. The Charpy V-notch testing of TC128B steel for cold temperature service that is addressed in the AAR standards and the HMR 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 fracture-resistance 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.

Therefore, as a result of this accident investigation, 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

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[3] 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.

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

> 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)
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> 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)
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> 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)
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> 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)
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> 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)
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> 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)

The Safety Board also issued a safety recommendation to the Canadian Pacific Railway. In your response to the recommendations in this letter, please refer to Safety Recommendations R-04-1 through -7. If you need additional information, you may call (202) 314-6177.

Chairman ENGLEMAN CONNERS, Vice Chairman ROSENKER, and Members CARMODY and HEALING concurred in these recommendations. Member GOGLIA did not participate.

Original Signed

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Chairman