# National Transportation Safety Board

Washington, D.C. 20594

## Safety Recommendation

**Date:** November 24, 1998

**In reply to refer to:** R-98-67 and -68

Honorable Jolene M. Molitoris
Administrator
Federal Railroad Administration
400 Seventh Street, S.W.
Washington, D.C. 20590

At 4:30 a.m., on April 2, 1997, tank car ACAX 80010 arrived at the Illinois Central Railroad yard in Memphis, Tennessee, on Illinois Central train No. GEME 01. At 12:05 p.m., a railroad inspector noticed leakage from the tank car during switching operations. The tank car was filled with anhydrous hydrogen fluoride, a corrosive and poisonous liquid.[1] Vapor appeared to be leaking from a weld at a 2- by 3-foot patch in the tank wall. About 150 people (26 residences) were evacuated from a ½-mile radius around the yard for about 17 hours while the leak was controlled and the material was transferred to another tank car. No injuries were reported.

The National Transportation Safety Board determined that the probable cause of the failure of tank car ACAX 80010 was inadequate heat treatment to reduce the hardness of the weld material used in the repair of the tank to a level that would retard or prevent hydrogen-assisted cracking and inadequate testing to determine whether the weld material hardness exceeded established limits.

Tank car ACAX 80010 had been loaded at Allied-Signal, Inc., (the tank car owner and shipper) in Geismar, Louisiana, on March 17, 1997, and it was shipped on March 31, 1997, destined for Cameco in Port Hope, Ontario, Canada. This was the first shipment of product in this

[1] Anhydrous hydrogen fluoride is a colorless liquid that fumes in air and has a sharp, pungent odor. The U.S. Department of Transportation (DOT) defines the material as a Class 8 (corrosive) with a poison-inhalation hazard and assigns it to Packing Group I, which contains materials that represent the greatest hazard in transportation within that class and therefore require the strongest packaging.

tank car since two hydrogen blisters[2] had been cut from the tank shell; one of the blisters was on the bottom near the middle of the tank where the 2- by 3-foot patch had been welded into the tank.

The repairs were performed by Texana Tank Car & Manufacturing, Inc., (Texana) of Nash, Texas, on February 24, 1997. The two blisters and the adjacent steel were cut out, and 1-inch-thick American Society for Testing and Materials (ASTM) A516, grade 70 steel patches were butt-welded in the openings. After the repair, Texana stress-relieved the welds and the heat-affected zones in the material on each side of the welds at temperatures above 1100° F (about 1150° F) for about 1 hour. The weld material on each patch was then tested for hardness at only two locations; one on the interior and one on the exterior of the tank. The recorded hardness readings for the patch near the middle of the tank, where the leak occurred, were Rockwell C 15 (exterior) and C 17 (interior).[3] Before tank car ACAX 80010 was returned to service, the welds were radiographed and no defects were observed. The tank car was also twice hydrostatically tested to the required test pressure of 400 psig without evidence of leakage before it was filled with anhydrous hydrogen fluoride.

Postaccident examination of the tank car revealed a vertical through-wall crack in the upper horizontal leg of one of the butt welds made during the February 1997 repair. The examination revealed that the fracture surface had a "river pattern," indicating that the fracture initiated from multiple locations along the weld crown on the interior surface of the tank car (adjacent to the anhydrous hydrogen fluoride). The crack propagated through the entire weld fusion zone, except for one exterior weld bead. The crack also propagated through portions of the heat-affected zones on both sides of the weld. In these zones, areas of flat circular fractures were centered around cavities containing inclusions in the steel. Postaccident testing revealed that the hardness of the weld material near the crack site ranged from Rockwell C 26 to C 32 and averaged Rockwell C 29.

E.I. DuPont de Nemours (DuPont) has studied the effect of anhydrous hydrogen fluoride on carbon steel vessels. One DuPont study[4] documented three types of damage caused by atomic hydrogen involved in corrosion: hydrogen-assisted stress corrosion cracking, stress-oriented hydrogen-induced cracking, and blistering. In each of these processes, anhydrous hydrogen fluoride reacts with the surface of carbon steel and releases atomic hydrogen. When released, atomic hydrogen can diffuse into the steel and pass through it. However, when a single hydrogen atom encounters an internal void space or a flaw (an inclusion) in the steel, it will combine with other atoms to form molecular hydrogen. Molecular hydrogen cannot pass through the steel and becomes trapped in the flaw. DuPont indicated that hydrogen-assisted stress corrosion cracking can occur rapidly and is known to attack weld material having a hardness above Rockwell C 22. Also, areas of flat circular fractures centered around cavities containing inclusions are typical of stress-oriented hydrogen-induced cracking, which can occur in the heat-affected zones of welds.

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[2] A hydrogen blister in steel is a bulge caused by molecular hydrogen trapped at an internal flaw within the steel.

[3] The Rockwell C hardness scale is used for rating the hardness of steels. Higher values indicate higher hardness.

[4] Schuyler, Roy L., III, Ph.D., *Hydrogen Blistering of Steel in Anhydrous Hydrofluoric Acid,* National Association of Corrosion Engineers, Houston, Texas, March 1979.

In the case of tank car ACAX 80010, given the initiation of the crack on the surface of the weld material exposed to the anhydrous hydrogen fluoride and the rapid propagation of the crack through the harder weld material, while the crack arrested in the lower hardness shell and patch material, the National Transportation Safety Board concludes that tank car ACAX 80010 failed because of the hydrogen-assisted cracking of the weld material for the repair patch in the tank shell. Given the susceptibility of high hardness weld material to hydrogen-assisted cracking and the rapid development of through cracks in tank cars transporting anhydrous hydrogen fluoride, the Safety Board believes that the FRA should inform all tank car repair facilities of the circumstances of this accident and urge these facilities to review and modify, if necessary, their practices for heat treatment and hardness testing of weld repairs to prevent additional tank car weld failures from hydrogen-assisted cracking.

While not directly related to the cause of this accident, damage caused by the third form of hydrogen-assisted cracking – blistering – necessitated the February 1997 repair on tank car ACAX 80010. Blistering, according to the DuPont study, primarily affects low-carbon steels and occurs when atomic hydrogen combines to form molecular hydrogen along well-developed planes of impurities in the steel. These planes of impurities usually run parallel to the surface, near the mid-plane of the steel plate. As molecular hydrogen forms along the planes of impurities, the pressure increases, eventually developing sufficiently to expand the flaw and separate a localized area in the steel into two thinner plates, distorting one of the exterior surfaces. The distortion is called a “blister.”

In 1979, DuPont provided information to the Association of American Railroads (AAR) that included material concerning the effect that anhydrous hydrogen fluoride has on carbon steel. Because of the information provided by DuPont, the AAR, with the help of the Chemical Manufacturers Association (CMA), began collecting information about hydrogen blistering in tank cars transporting anhydrous hydrogen fluoride. A March 13, 1985, letter from the CMA to the AAR stated that 132 of the 212 tank cars in anhydrous hydrogen fluoride service had been inspected and that the inspections indicated that hydrogen blisters developed slowly in most tank car materials. The letter also stated that blisters could be identified during the required periodic visual inspections and repaired before they threatened tank car integrity. However, the letter indicated that tank cars manufactured of TC 128 steel were the exception to this rule because 22 of the 29 TC 128 steel tank cars inspected had developed hydrogen blisters after only 3 years in anhydrous hydrogen fluoride service.

On the basis of this information, in 1987, the AAR amended the AAR *Manual of Standards and Recommended Practices* (M-1002) to forbid the use of TC 128 steel for repair patches on tank cars in anhydrous hydrogen fluoride service and to forbid the conversion of tank cars made of TC 128 steel to anhydrous hydrogen fluoride service. The new AAR standards also limited the types of steels that could be used in the manufacture of new tank cars for anhydrous hydrogen fluoride service to specification ASTM A516-71, grade 70 normalized steel, and ASTM A537-69, class 1 (normalized) steel. The new standards effectively forbade the use of TC 128 steel in new tank car construction. They did not, however, limit the use of those tank cars made of TC 128 steel that were already in anhydrous hydrogen fluoride service.

The AAR could not provide information on why the prohibition was not applied to tank cars already in anhydrous hydrogen fluoride service. The March 1985 CMA letter, however, had stated that only one tank car made of TC 128 steel was still in anhydrous hydrogen fluoride service and that the industry had no intention of placing additional cars made of that steel in this service. This statement may have been interpreted as an indication that the industry was removing all tank cars made of TC 128 steel from anhydrous hydrogen fluoride service.

Tank car ACAX 80010, a DOT specification 112A400W tank car, [5] was constructed of TC 128 steel. It was 1 of 26 tank cars made of TC 128 steel that had been transferred in 1994 from the Allied-Signal, Inc., Amherstburg fleet in Canada to the company's fleet in Geismar, Louisiana.[6] These tank cars were in Canada when the CMA study was conducted; therefore, it is probable that they were not included in the study.

Allied-Signal, Inc.'s, records of its 26 tank cars made of TC 128 steel do not indicate rapid development of hydrogen blisters in these tanks. In fact, the inspections of tank car ACAX 80010, which had been manufactured in 1971, did not reveal large internal hydrogen blisters until 1996, about 25 years after the tank car was manufactured. However, the Board's investigation revealed a recent increase in the frequency of blister development in this tank car. No blisters were observed during a 1991 inspection, but two were found during a 1996 inspection. During a 1998 postaccident inspection, four additional blisters were discovered.

Given that exposure of TC 128 steel to anhydrous hydrogen fluoride is known to cause the formation of hydrogen blisters that could weaken areas in the tank shell, that the AAR has prohibited the use of TC 128 steel for the construction of new tank cars and for the repair of existing tank cars used to transport anhydrous hydrogen fluoride, that older tank cars made of TC 128 steel may be experiencing an increased frequency of blister development, and that the DOT has assigned anhydrous hydrogen fluoride to those materials (Packing Group I) within the corrosive classification that represent the greatest hazard in transportation and require the strongest packaging, the Safety Board concludes that the use of tank cars made of TC 128 steel is not appropriate for the transportation of anhydrous hydrogen fluoride. Therefore, the Safety Board believes that the FRA should prohibit the transportation of anhydrous hydrogen fluoride in tank cars manufactured of TC 128 steel.

As a result of this investigation, the National Transportation Safety Board recommends that the Federal Railroad Administration:

> Inform all tank car repair facilities of the circumstances of the April 2, 1997, failure of a railroad tank car and release of anhydrous hydrogen fluoride in Memphis, Tennessee, and urge them to review and modify, if necessary, their practices for heat treatment and hardness testing of weld repairs to prevent additional tank car weld failures from hydrogen-assisted cracking. (R-98-67)
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> Prohibit the transportation of anhydrous hydrogen fluoride in tank cars manufactured of TC 128 steel. (R-98-68)

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[5] In 1990, head shields were added to the tank car, and it was converted to a specification 112S400W car.

[6] Information provided by Allied-Signal, Inc., since the accident indicates that the 26 tank cars have been returned to Canada.

Please refer to Safety Recommendations R-98-67 and -68 in your reply. If you need additional information, you may call (202) 314-6463.

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

*[original signed]*

By: Jim Hall
Chairman