Log P-317B

# National Transportation Safety Board

Washington, D.C. 20594

## Safety Recommendation

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**In reply refer to:** P-98-7 through -9

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Despite the general acceptance of plastic piping as a safe and economical alternative to piping made of steel or other materials, the Safety Board notes that a number of pipeline accidents it has investigated have involved plastic piping that cracked in a brittle-like manner. For example, on October 17, 1994, an explosion and fire in Waterloo, Iowa, destroyed a building and damaged other property. Six persons died and seven were injured in the accident. The Safety Board investigation determined that natural gas had been released from a plastic service pipe that had failed in a brittle-like manner at a connection to a steel main.

The Safety Board also investigated a gas explosion that resulted in 33 deaths and 69 injuries in San Juan, Puerto Rico, in November 1996.[1] The Safety Board's investigation determined that the explosion resulted from ignition of propane gas that had migrated under pressure from a failed plastic pipe that displayed evidence of brittle-like circumferential cracking.

The Railroad Commission of Texas investigated a natural gas explosion and fire that resulted in one fatality in Lake Dallas, Texas, in August 1997.[2] A metal pipe pressing against a plastic pipe generated stress intensification that led to a brittle-like crack in the plastic pipe.

A broader Safety Board survey of the accident history of plastic piping suggested that the material may be susceptible to premature brittle-like cracking under conditions of stress intensification. No statistics exist that detail how much and from what years any plastic piping may already have been replaced; however, hundreds of thousands of miles of plastic piping have been installed, with a significant amount of it having been installed prior to the mid-1980s. Any

[1]For more information, see National Transportation Safety Board Pipeline Accident Report--*San Juan Gas Company, Inc./Enron Corp., Propane Gas Explosion in San Juan, Puerto Rico, on November 21, 1996* (NTSB/PAR-97/01).

[2]Railroad Commission of Texas Accident Investigation No. 97-AI-055, October 31, 1997.

vulnerability of this material to premature failure could represent a serious potential hazard to public safety.

In an attempt to gauge the extent of brittle-like failures in plastic piping and to assess trends and causes, the Safety Board examined pipeline accident data compiled by the Research and Special Programs Administration (RSPA). The examination revealed that the data were insufficient to serve as a basis for assessing the long-term performance of plastic pipe.

Lacking adequate data from RSPA, the Safety Board reviewed published technical literature and contacted more than 20 experts in gas distribution plastic piping to determine the estimated frequency of brittle-like cracks in plastic piping. The majority of the published literature and experts indicated that failure statistics would be expected to vary from one gas system operator to another based on factors such as brands and dates of manufacture of plastic piping in service, installation practices, and ground temperatures, but they indicated that brittle-like failures, as a nationwide average, may represent the second most frequent failure mode for older plastic piping, exceeded only by excavation damage.

The Safety Board asked several gas system operators about their direct experience with brittle-like cracks. Four major gas system operators reported that they had compiled failure statistics sufficient to estimate the extent of brittle-like failures. Three of those four said that brittle-like failures are the second most frequent failure mode in their plastic pipeline systems. One of these operators supplied data showing that it experienced at least 77 brittle-like failures in plastic piping in 1996 alone.

As an outgrowth of the Safety Board's investigations into the Waterloo, Iowa; San Juan, Puerto Rico; and about a dozen other accidents, and in view of indications that some plastic piping, particularly older piping, may be subject to premature failure attributable to brittle-like cracking, the Safety Board undertook a special investigation of polyethylene gas service pipe. The investigation addressed the following safety issues:[3]

- The vulnerability of plastic piping to premature failures due to brittle-like cracking;
- The adequacy of available guidance relating to the installation and protection of plastic piping connections to steel mains; and
- Performance monitoring of plastic pipeline systems as a way of detecting unacceptable performance in piping systems.

The Waterloo, San Juan, and Lake Dallas accidents were only three of the most recent in a series of accidents in which brittle-like cracks in plastic piping have been implicated. In Texas in 1971, natural gas migrated into a house from a brittle-like crack at the connection of a plastic

[3]For more information, see National Transportation Safety Board Pipeline Special Investigation Report--*Brittle-like Cracking in Plastic Pipe for Gas Service* (NTSB/SIR-98/01).

service line to a plastic main.[4] The gas ignited and exploded, destroying the house and burning one person. The investigation determined that vertical loading over the connection generated long-term stress that led to the crack.

A 1973 natural gas explosion and fire in Maryland severely damaged a house, killed three occupants, and injured a fourth.[5] The Safety Board's investigation revealed that a brittle-like crack occurred in a plastic pipe as a result of an occluded particle that created a stress point.

The Safety Board's investigation of a natural gas explosion and fire that resulted in three fatalities in North Carolina in 1975[6] determined that the gas had accumulated because a concrete drain pipe resting on a plastic service pipe had precipitated two cracks in the plastic pipe. Available documentation suggests that these cracks were brittle-like.

A 1978 natural gas accident in Arizona destroyed 1 house, extensively damaged 2 others, partially damaged 11 other homes, and resulted in 1 fatality and 5 injuries.[7] Available documentation indicates that the gas line crack that caused the accident was brittle-like.

A 1978 accident in Nebraska involved the same brand of plastic piping as that involved in the Waterloo accident. A crack in a plastic piping fitting resulted in an explosion that injured one person, destroyed one house, and damaged three other houses.[8] The Safety Board determined that inadequate support under the plastic fitting resulted in long-term stress intensification that led to the formation of a circumferential crack in the fitting. Available documentation indicates that the crack was brittle-like.

A December 1981 natural gas explosion and fire in Arizona destroyed an apartment, damaged five other apartments in the same building, damaged nearby buildings, and injured three occupants.[9] The Safety Board's investigation determined that assorted debris, rocks, and chunks of concrete in the excavation backfill generated stress intensification that resulted in a circumferential crack in a plastic pipe at a connection to a plastic fitting. Available documentation indicates that the crack was brittle-like.

A July 1982 natural gas explosion and fire in California destroyed a store and two residences, severely damaged nearby commercial and residential structures, and damaged

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[4]National Transportation Safety Board Pipeline Accident Report--*Lone Star Gas Company, Fort Worth, Texas, October 4, 1971* (NTSB/PAR-72/5).

[5]National Transportation Safety Board Pipeline Accident Report--*Washington Gas Light Company, Bowie, Maryland, June 23, 1973* (NTSB/PAR-74/5).

[6]National Transportation Safety Board Pipeline Accident Brief--"Natural Gas Corporation, Kinston, North Carolina, September 29, 1975."

[7]National Transportation Safety Board Pipeline Accident Brief--"Arizona Public Service Company, Phoenix, Arizona, June 30, 1978."

[8]National Transportation Safety Board Pipeline Accident Brief--"Northwestern Public Service, Grand Island, Nebraska, August 28, 1978."

[9]National Transportation Safety Board Pipeline Accident Brief--"Southwest Gas Corporation, Tucson, Arizona, December 3, 1981."

automobiles.[10] The Safety Board's investigation identified a longitudinal crack in a plastic pipe as the source of the gas leak that led to the explosion. Available documentation indicates that the crack was brittle-like.

A September 1983 natural gas explosion in Minnesota involved the same brand of plastic piping as that involved in the Waterloo and Nebraska accidents.[11] The explosion destroyed one house and damaged several others, and injured five persons. The Safety Board's investigation determined that rock impingement generated stress intensification that resulted in a crack in a plastic pipe. Available documentation indicates that the crack was brittle-like.

One woman was killed and her 9-month-old daughter injured in a December 1983 natural gas explosion and fire in Texas.[12] The Safety Board's investigation determined that the source of the gas leak was a brittle-like crack that had resulted from damage to the plastic pipe during an earlier squeezing operation to control gas flow.[13]

A September 1984 natural gas explosion in Arizona resulted in five fatalities, seven injuries, and two destroyed apartments.[14] The Safety Board's investigation determined that a reaction between a segment of plastic pipe and some liquid trapped in the pipe weakened the pipe and led to a brittle-like crack.

Excavations following the Waterloo, Iowa, accident uncovered, at a depth of about 3 feet, a 4-inch steel main.[15] Welded to the top of the main was a steel tapping tee. Connected to the steel tee was a 1/2-inch plastic service pipe. Markings on the plastic pipe indicated that it was a medium-density polyethylene material manufactured on June 11, 1970, in accordance with American Society for Testing and Materials (ASTM) standard D2513. The pipe had been marketed by Century Utility Products, Inc. (Century). The plastic pipe was found cracked at the end of the tee's internal stiffener and beyond the coupling nut.

The investigation determined that much of the top portion of the circumference of the pipe immediately outside the tee's internal stiffener displayed several brittle-like slow crack initiation and growth fracture sites. These slow crack fractures propagated on almost parallel planes slightly offset from each other through the wall of the pipe. As the slow cracks from different planes continued to grow and began to overlap one another, ductile tearing occurred

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[10]National Transportation Safety Board Pipeline Accident Brief--"Pacific Gas and Electric Company, San Andreas, California, July 8, 1982."

[11]National Transportation Safety Board Pipeline Accident Brief--"Northern States Power Company, Newport, Minnesota, September 19, 1983."

[12]National Transportation Safety Board Pipeline Accident Brief--"Lone Star Gas Company, Terell, Texas, December 9, 1983."

[13]Plastic pipe is sometimes squeezed to control the flow of gas. In some cases, squeezing plastic pipe can damage it and make it more susceptible to brittle-like cracking.

[14]National Transportation Safety Board Pipeline Accident Report--*Arizona Public Service Company Natural Gas Explosion and Fire, Phoenix, Arizona, September 25, 1984* (NTSB/PAR-85/01).

[15]For more information, see Pipeline Accident Brief in appendix to National Transportation Safety Board Pipeline Special Investigation Report--*Brittle-like Cracking in Plastic Pipe for Gas Service*.

between the planes. Substantial deformation was observed in part of the fracture; however, the initiating cracks were still classified as brittle-like.

Samples recovered from the plastic service line underwent several laboratory tests under the supervision of the Safety Board. Two of these tests were meant to roughly gauge the pipe's susceptibility to brittle-like cracking. These tests were a compressed ring environmental stress crack resistance (ESCR) test in accordance with ASTM F1248 and a notch tensile test known as a PENT test that is now ASTM F1473. Lower failure times in these tests indicate a greater susceptibility to brittle-like cracking under the test conditions. The ESCR testing of 10 samples from the pipe yielded a mean failure time of 1.5 hours, and the PENT testing of 2 samples yielded failure times of 0.6 and 0.7 hours. Test values this low have been associated with materials having poor performance histories[16] characterized by high leakage rates at points of stress intensification due to crack initiation and slow crack growth typical of brittle-like cracking.

The Safety Board has investigated two other pipelines accidents, one in Nebraska in 1978 and one in Minnesota in 1983, that involved Century piping. The Safety Board is also aware of four other accidents that it did not investigate that involved the same brand of piping.

The Century pipe involved in the Waterloo accident was made from Union Carbide's DHDA 2077 Tan resin. Although Union Carbide's laboratory data supported Union Carbide's claimed strength, the Safety Board's review of the same data showed that the material had an early ductile-to-brittle transition, indicating poor resistance to brittle-like fractures.

As a result of its investigation of the Waterloo accident, the Safety Board made the following safety recommendation to the Research and Special Programs Administration (RSPA)

> Notify pipeline system operators who have installed polyethylene gas piping extruded by Century Utility Products, Inc., from Union Carbide Corporation DHDA 2077 Tan resin of the piping's poor brittle-crack resistance, and require these operators to develop a plan to closely monitor the performance of this product and to take any action necessary to ensure that the presence of this piping in a gas system is not now and does not become a threat to public safety. (P-98-1)

As you know, in the early years, the procedure used to rate the strength of plastic piping material assumed that the gradual decline in the strength of plastic piping material as it was subjected to stress over time would continue to be described by a straight line. As you are equally aware, however, elevated-temperature testing has indicated that polyethylene piping can exhibit a decline in strength that does not follow a straight line path, but instead is described by a

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[16]Uralil, F. S., et al., *The Development of Improved Plastic Piping Materials and Systems for Fuel Gas Distribution—Effects of Loads on the Structural and Fracture Behavior of Polyolefin Gas Piping*, Gas Research Institute Topical Report, 1/75 - 6/80, NTIS No. PB82-180654, GRI Report No. 80/0045, 1981; Hulbert, L. E., Cassady, M. J., Leis, B. N., Skidmore, A., *Field Failure Reference Catalog for Polyethylene Gas Piping, Addendum No 1*, Gas Research Institute Report No. 84/0235.2, 1989; and Brown, N. and Lu, X., "Controlling the Quality of PE Gas Piping Systems by Controlling the Quality of the Resin," *Proceedings, Thirteenth International Plastic Fuel Gas Pipe Symposium*, pp 327-338, American Gas Association, Gas Research Institute, Battelle Columbus Laboratories, 1993.

downturn. The difference between the actual (falloff) and projected (straight line) strengths became even more pronounced as the lines were extrapolated beyond 100,000 hours.

Piping manufacturers have addressed this issue by improving their formulations to delay onset of the downturn in strength. At the same time, the procedure was improved to reflect the fact that elevated-temperature testing, by accelerating the fracture process, provided a good representation of the true long-term strength of the tested material at 73 °F. The combination of more durable modern plastic piping materials and more realistic strength testing has rendered the strength ratings of modern plastic piping fairly reliable. Unfortunately, much of the early plastic piping was sold and installed with expectations of strength and long-term performance that, because they were based on questionable assumptions about long-term performance, may not have been valid. This is borne out by data from a variety of sources. The history of strength rating requirements, a review of the piping properties and literature, and observations of several experts with extensive experience in plastic piping, all suggest that much of the polyethylene pipe, depending upon the brands, manufactured from the 1960s through the early 1980s fails at lower stresses and after less time than originally projected. The Safety Board therefore concluded that the procedure used in the United States to rate the strength of plastic pipe may have overrated the strength and resistance to brittle-like cracking of much of the plastic pipe manufactured and used for gas service from the 1960s through the early 1980s.

As a result of this finding, the Safety Board made the following safety recommendation to RSPA:

> Determine the extent of the susceptibility to premature brittle-like cracking of older plastic piping (beyond that piping marketed by Century Utility Products, Inc.) that remains in use for gas service nationwide. Inform gas system operators of the findings and require them to closely monitor the performance of the older plastic piping and to identify and replace, in a timely manner, any of the piping that indicates poor performance based on such evaluation factors as installation, operating, and environmental conditions; piping failure characteristics; and leak history. (P-98-2)

Premature brittle cracking in plastic piping is a complex phenomenon. Without clear and straightforward communication to pipeline operators about brands of piping and conditions that increase the likelihood of brittle cracking, many pipeline operators may not have the knowledge to make good decisions affecting public safety. Some of these key decisions include how often to conduct leak surveys and whether to repair or replace portions of pipeline systems.

Frequently, piping manufacturers, because they can receive feedback from a number of customers, are the first to learn of systemic problems with their products. For small operators, contact with a manufacturer may be the major source of outside communication about poorly performing products. Unfortunately, while manufacturers have a high degree of technical expertise regarding their products, the Safety Board is aware of only a very few cases in which manufacturers of resin or pipe have formally notified the gas industry of materials having poor resistance to brittle cracking.

Furthermore, perhaps because the possibility of premature failure of plastic piping due to brittle-like cracking has not been fully appreciated within the industry and the scope of the potential problem has not been fully measured, the Federal Government has not provided information on this issue to gas system operators. The Safety Board concluded that gas pipeline operators have had insufficient notification that much of the plastic pipe manufactured and used for gas service from the 1960s through the early 1980s may be susceptible to brittle-like cracking and therefore may not have implemented adequate pipeline surveillance and replacement programs for their older piping. In the view of the Safety Board, manufacturers of resin and pipe should do more to notify pipeline operators about the poor brittle-crack resistance of some of their past products.

Stress intensification has been an element common to many plastic gas pipeline accidents investigated by the Safety Board. Based on evidence examined by the Safety Board, the premature transition of plastic piping from ductile failures to brittle failures appears to have little observable adverse impact on the serviceability of plastic piping except in those instances in which the piping is subjected to external forces. Unfortunately, stress intensification, which can take many forms, has been found in a number of gas piping systems. Rock impingement, soil settlement, and excess pipe bending are among the potential sources of stress intensification, and the combination of piping with poor resistance to brittle-like cracking and external forces can lead to significant rates of failures. These failures can, in turn, lead to serious accidents. The Safety Board therefore concluded that much of the plastic pipe manufactured and used for gas service from the 1960s through the early 1980s may be susceptible to premature brittle-like failures when subjected to stress intensification, and these failures represent a potential public safety hazard.

Examples of conditions that can generate stress intensification include differential earth settlement, particularly at connections with more rigidly anchored fittings; excessive bending as a result of installation configurations, especially at fittings; and point contact with rocks or other objects. The Safety Board special investigation determined that much of the available guidance to gas system operators for limiting stress intensification at plastic pipeline connections to steel mains is inadequate or ambiguous. Based on its review of this guidance and on the history of the plastic pipeline accidents it has investigated, the Safety Board concluded that, because guidance covering the installation of plastic piping is inadequate for limiting stress intensification at plastic service connections to steel mains, many of these connections may have been installed without adequate protection from shear and bending forces.

The gas service involved in the Waterloo, Iowa, accident was installed with a horizontal bend that was sharper than that recommended by current gas industry guidance recommendations; however, the bend may have been installed in the direction of the residual coil bend. Gas industry recommendations do not address residual bending in the pipe, even though plastic piping is often delivered to job sites in banded coils, which leaves some residual bending in the piping even after the bands are removed. Installing coiled pipe with any necessary bending in the direction of the residual bend may be a good practice to limit stresses. Conversely, bending pipe against the direction of the residual coil bend, even if the resulting bend is in accordance with gas industry recommendations, will induce greater stresses.

The National Transportation Safety Board therefore makes the following safety recommendations to the Plastics Pipe Institute:

> Advise your members to notify pipeline system operators if any of their piping products, or materials used in the manufacture of piping products, currently in service for natural gas or other hazardous materials indicate poor resistance to brittle-like failure. (P-98-7)
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> Advise your plastic pipe manufacturing members to develop and publish recommendations for limiting shear and bending forces at plastic service pipe connections to steel mains. (P-98-8)
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> Advise your plastic pipe manufacturing members to revise their pipeline bend radius recommendations as necessary to take into account the effects of residual coil bends in plastic piping. (P-98-9)

Also, the National Transportation Safety Board issued Safety Recommendations P-98-1 through -5 to the Research and Special Programs Administration; P-98-6 to the Gas Research Institute; P-98-10 to the Gas Piping Technology Committee; P-98-11 and -12 to the American Society for Testing and Materials; P-98-13 to the American Gas Association; P-98-14 and -15 to MidAmerican Energy Corporation; P-98-16 and -17 to Continental Industries, Inc.; P-98-18 to Dresser Industries, Inc.; P-98-19 to Inner-Tite Corporation; and P-98-20 to Mueller Company.

The National Transportation Safety Board is an independent Federal agency with the statutory responsibility "to promote transportation safety by conducting independent accident investigations and by formulating safety improvement recommendations" (Public Law 93-633). The Safety Board is vitally interested in any action taken as a result of its safety recommendations. Therefore, it would appreciate a response from you regarding action taken or contemplated with respect to the recommendations in this letter. Please refer to Safety Recommendations P-98-7 through -9 in your reply. If you need additional information, you may call (202) 314-6469.

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

By: Jim Hall
Chairman