



Log P-317A

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

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In reply refer to: P-98-6

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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

¹For 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).

²Railroad 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

³For 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 1975⁶ 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

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

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

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

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

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

⁹National 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 chemical reaction between a segment of plastic pipe and some liquid trapped in the pipe weakened the pipe and led to a brittle-like crack.

The procedure used in the United States to rate the strength of plastic pipe, which was developed in the early 1960s, involved subjecting test piping to different stress values and recording how much time elapsed before the piping ruptured. The stress rupture data of the samples were then plotted, and a best-fit straight line was derived to represent the material's decline in rupture resistance as its time under stress increased.

To meet the requirements of the procedure, at least one tested sample had to be able to withstand stress rupture testing until at least 10,000 hours, or slightly more than 1 year. The straight line that was plotted to describe the data for this material was extrapolated out by a factor of 10, to 100,000 hours (about 11 years). The point at which the sloping straight line intersected the 100,000-hour point indicated the appropriate hydrostatic design basis for this material.

A key assumption characterized the assignment of a hydrostatic design basis under the procedure: The procedure 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.

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

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

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

¹³Plastic 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.

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

In the early 1960s, the industry had had little long-term experience with plastic piping, and a straight line seemed to represent the response of the material to laboratory stress testing. With little other information on which to base strength estimations, the straight-line assumption appeared valid. This procedure and assumption for rating the strength was incorporated into industry and government requirements.

As experience grew with plastic piping materials and as better testing methods were developed, however, the straight-line assumptions of the procedure came to be challenged. Elevated-temperature testing indicated that polyethylene piping can exhibit a decline in strength that does not follow a straight line path, but instead is described by a 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.

The combination of more durable modern plastic piping materials and more realistic strength testing has rendered the strength ratings of modern plastic piping much more 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.

Another important assumption of the design protocol for plastic pipe involved the ductility of the materials. It was assumed, based on short-term tests, that plastic piping had long-term ductile properties. Ductile material, by bending, expanding, or flexing, can redistribute stress concentrations better than can brittle material, such as cast iron. Notable from results of tests performed under the strength-rating procedure was that those short-term stress ruptures in the testing process tended to be characterized by substantial material deformation in the area of the rupture. This deformation described a material with obvious ductile properties. However, it was shown that, as time-to-failure increased in stress rupture tests, failures in several materials occurred as slit failures that, because they were not accompanied by substantial deformation, were more typical of brittle-like failures. These slit or brittle-like failures were characterized by crack initiation and slow crack growth. The procedure used to rate the strength of plastic pipe did not distinguish between ductile fractures and slit fractures and assumed that both types of failures would be described by the same straight line.

The assumption of ductility of plastic piping had important safety ramifications. For example, a number of experts believed it was safe to design plastic piping installations based on stresses primarily generated by internal pressure and to give less consideration to stress

intensification generated by external loading. Ductile material reduces stress intensification by localized yielding, or deformation.

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 undamaged piping is subjected to stress intensification generated by 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.

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.

Over a number of years, the GRI sponsored research projects investigating various tests and performance characteristics of polyethylene piping materials. Among these projects was a series of research investigations directed at exploring the fracture mechanics principles behind crack initiation and slow crack growth. These investigations led to the development of slow crack growth tests. The research studies frequently identified the piping and resins studied by codes rather than by specific materials, manufacturers, or dates of manufacture. In 1984, the GRI published a study¹⁵ that compared and ranked several commercially extruded polyethylene piping materials produced after 1971. This study also included several stress rupture curves showing early transitioning from ductile to brittle failure modes. Again, the materials tested were identified by codes.

In short, the GRI has developed a significant amount of data on older plastic piping, but it has frequently published the data in codified terms. Without a way to associate codes with specific products, the average gas pipeline operator could not make effective use of the data.

The National Transportation Board therefore makes the following safety recommendation to the Gas Research Institute:

¹⁵Cassady, M. J., Uralil, F. S., Lustiger, A., Hulbert, L. E., *Properties of Polyethylene Gas Piping Materials Topical Report (January 1973 - December 1983)*, GRI Report 84/0169, Gas Research Institute, Chicago, IL, 1984.

Publish the codes used to identify plastic piping products in previous Gas Research Institute studies to make the information contained in these studies more useful to pipeline system operators. (P-98-6)

Also, the National Transportation Safety Board issued Safety Recommendations P-98-1 through -5 to the Research and Special Programs Administration; P-98-7 through -9 to the Plastics Pipe 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 recommendation in this letter. Please refer to Safety Recommendation P-98-6 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 this recommendation.

By:


Jim Hall
Chairman