Hazard Analysis and Mitigation Report

Aldyl A Polyethylene Gas Pipelines

June 11, 2014

Hazard Analysis & Mitigation Report On Aldyl A Polyethylene Gas Pipelines in California

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ABOUT HAZARD ANALYSIS AND MITIGATION REPORTS

This paper is the first in a series of Hazard Analysis and Mitigation Reports. Prepared by the staff of the California Public Utilities Commission, the purpose of the Hazard Analysis and Mitigation Reports is to examine potential hazards in California gas and electric utility operations. The report seeks to understand each utility's approach to mitigate the risks posed by the hazard. The reports provide hazard-specific background knowledge and technical analysis.

A Hazard Analysis and Mitigation Report is premised on the theory that an inadequate risk assessment and management response to an otherwise moderately hazardous situation may well be more dangerous than an adequate response to an inherently more hazardous situation. Therefore, Hazard Analysis and Mitigation Reports will include recommendations to decision-makers for policy improvements and to the utility operators as to different types of best practices with respect to the particular hazard. The Commission's staff intends to have these reports serve as an important forward-looking tool to help prevent incidents from occurring.

INTRODUCTION

With heightened public awareness on gas pipeline safety in California, one topic that has received much public attention of late is the potential hazard associated with a type of polyethylene (PE) gas pipeline called Aldyl A. This is understandable, considering that one of the most devastating gas pipeline incidents, occurring on November 21, 1996 in San Juan, Puerto Rico, where thirty-three people were killed and at least sixty-nine were injured, was caused by a small slit fracture (Figure 1) on a small section of Aldyl A plastic gas service line.[1] This heightened awareness was further stoked by two gas incidents in Cupertino (Aug. 31, 2011) and Roseville (Sept. 27, 2011) that happened in quick succession involving Aldyl A pipes.[2,3] On March 14, 2012, early vintage Aldyl A pipes were identified as a major potential hazard affecting gas pipeline safety in a report prepared by the staff of the California Public Utilities Commission (CPUC).[4]

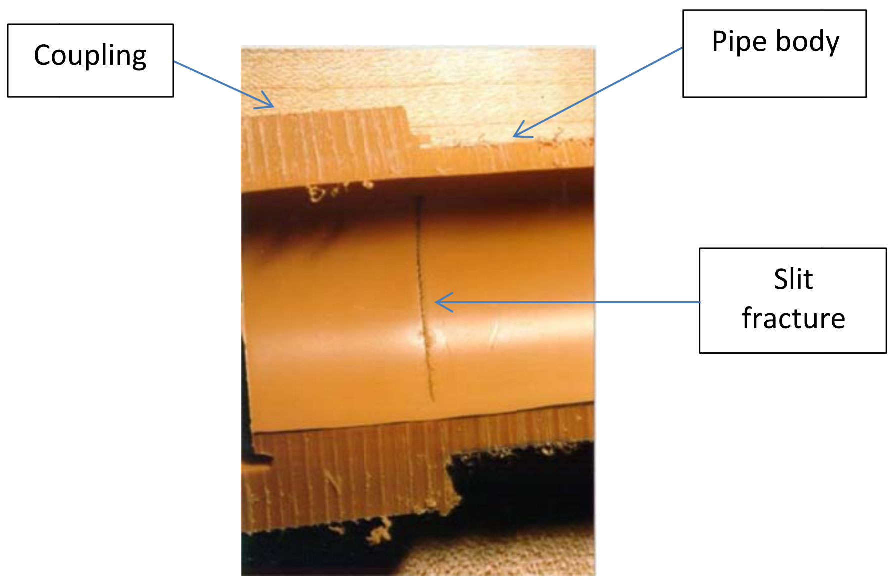

Figure 1: Enlarged view showing slit fracture on the interior of 1¼ Inch Aldyl A service pipe involved in the San Juan incident

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[1] NTSB report on San Juan incident: http://www.ntsb.gov/doclib/reports/1997/PAR9701.pdf
[2] http://www.sfgate.com/news/article/Plastic-natural-gas-pipe-failure-data-kept-secret-2308629.php
[3] http://www.sfgate.com/bayarea/article/New-PG-E-blast-involved-problematic-plastic-2298864.php
[4] Risk Assessment Section Hazard Database Project, Report on Status and Initial Recommendations, March 14, 2012: http://www.cpuc.ca.gov/NR/rdonlyres/381B6603-37A4-48C0-A1B7-D4A56928F6CC/0/RiskAssessmentMarch2012ReportFINAL.pdf

As continuation of the effort initiated in the March 14, 2012 report, this paper examines the current status of the danger of potential failure due to slow crack growth associated with early generation Aldyl A PE pipes among major gas distribution operators under the CPUC's jurisdiction. This study encompasses the gas distribution operations of the Pacific Gas & Electric Company (PG&E), Southern California Gas Company (SoCalGas), San Diego Gas & Electric (SDG&E), Southwest Gas (SWG), and the propane system on Catalina Island owned and operated by Southern California Edison (SCE). The West Coast Gas Company and gas storage field operators are excluded from this study due to the absence of Aldyl A pipes from their systems. Municipalities, mobile home park gas systems, and small propane distribution systems are also excluded from this study.

The intent of this study is to examine the current inventory of Aldyl A pipes among the major California gas operators and the different strategies that these gas operators use to identify and mitigate the risks associated with older vintage Aldyl A pipes in order to see whether any common observations of deficiencies and recommendations for improvement can be made in order to enhance public safety. As part of the process, we examine the gas pipeline operators' knowledge of the extent of the problems posed by early vintage Aldyl A pipes and the adequacy of the operators' response.

HISTORY OF ALDYL A PIPES

This section describes the history and different vintages of Aldyl A pipes.[5]

Origin of the Aldyl A name

Aldyl® "A" is a trademarked name referring to a finished polyethylene pipeline product manufactured by the DuPont chemical company using DuPont's own proprietary Alathon®

[5] Information in this section was derived in large part from "Managing Aldyl 'A' PE Pipe in the Avista Natural Gas Distribution System" by Kristen Busko, Avista Utilities and Dr. Gene Palermo, Palermo Plastics Pipe Consulting.

polymer resin. (We will refer to it simply as Aldyl A throughout the rest of this paper.) Until the Aldyl A product line was acquired from DuPont by the Uponor company in 1991, no other manufacturers used this resin to produce pipelines under this or other trade names. The term pipeline in this context can refer to either the pipes or the fittings attached to the pipes made of an Alathon resin. This paper will deal with only Aldyl A products sold under the DuPont label.

The name "Aldyl" also has an interesting etymology. Prior to the introduction of Aldyl A pipes, the DuPont chemical company was manufacturing a bi-layer polyethylene/polyacetal pipeline product using Alathon polyethylene resin and Delrin® polyacetal resin. DuPont initially called this product "Aldel" as a portmanteau of **Al**athon and **Del**rin, in deference to the heritage of these two components in DuPont's product lines. To prevent confusion of "Aldel" with an existing trade name, "del" was changed to "dyl" and the trademark Aldyl® was born. In 1965, DuPont began to make gas pipes using PE only and called this pipe Aldyl® "A".

Vintage: 1965-1970

Aldyl A pipeline products were first introduced to the market in 1965. The initial PE resin from which Aldyl A was manufactured between 1965 and 1970 was Alathon 5040.

Vintage: 1970-1983

In 1970, DuPont discontinued the use of Alathon 5040 and began to manufacture Aldyl A pipes using an improved resin, Alathon 5043, due to the latter's higher density and resulting improved resistance to rupture. Alathon 5043 became the primary PE resin DuPont used to manufacture Aldyl A pipes from 1970 to 1983. It was also during this period that DuPont discovered during elevated temperature stress rupture testing that some Aldyl A pipe samples made of Alathon 5043 resin between 1970 and 1972 had what is now known as Low Ductile Inner Wall (LDIW) characteristics that resulted from excessive temperature settings during the extrusion process. This manufacturing issue affected only Aldyl A pipes made of Alathon 5043 resin during the 1970 to 1972 period and approximately 30% to 40% of pipes in this group were affected. Samples with LDIW characteristics have an oxidized inner surface that predisposes the inner surface to initiate cracks faster. The resulting shortened crack initiation time leads to dramatically reduced overall pipeline longevity through a failure mechanism known as slow crack growth. There are no simple non-destructive tests that may be employed in the field to distinguish LDIW Aldyl A pipes from non-LDIW Aldyl A pipes. However, LDIW samples can be easily identified by a simple destructive testing procedure called a reverse bend test, in which a short cutout strip of pipe sample is bent sharply backwards. Samples with LDIW characteristics would show an immediate crazing pattern on the inner surface during the reverse bend test. When reviewing Aldyl A pipes of this vintage, visual inspection will not distinguish between LDIW and non-LDIW pipes due to their identical external appearance.

Another term often used in conjunction with the slow crack growth mechanism is "brittle-like cracking," which describes the relatively smooth fracture surfaces on a slowly growing crack as having the appearance characteristic of brittle fracture propagation. Compounding the problem of LDIW is the fact that Alathon 5043 resin has moderately low resistance to slow crack growth compared to later generation, improved Alathon resins.

Aldyl A PE pipes made by DuPont with LDIW characteristics are not the only plastic pipes with low resistance to slow crack growth. What sets the LDIW Aldyl A pipes apart from other types of plastic pipes with similarly low resistance to slow crack growth is that the brittle inner surface of LDIW pipes expedites crack initiation when external stresses are applied to the pipe. In polyethylene pipes, the crack initiation time typically accounts for 70% to 90% of the total time to failure upon application of a stress. Since the overall time to failure of a pipeline segment by slow crack growth is the sum of the crack initiation time and the crack propagation time, pipes with lower initiation time to crack formation, such as LDIW Aldyl A, would experience much higher rates of failure from slow crack growth. Aldyl A pipes made of Alathon 5043 with LDIW characteristics have a median projected time to failure only 1/10th that of Aldyl A pipes made of Alathon 5043 resin that have no LDIW characteristics.

Vintage: 1983-1988

In 1983, DuPont again changed the resin formulation, this time from Alathon 5043 to Alathon 5046-C. This new resin formulation offered an order of magnitude improvement in resistance to slow crack growth and long term performance over Alathon 5043. In accelerated stress testing in laboratory conditions, Alathon 5046-C offers a ten-fold increase in median time to failure over non-LDIW Alathon 5043. DuPont marketed Aldyl A pipes made of 5046-C as "Improved Aldyl A."

Vintage: 1988-1992

In 1988, DuPont offered yet another improvement in the Alathon series of resins, changing from Alathon 5046-C to Alathon 5046-U. This improved resin offered yet another ten-fold increase in median time to failure over its predecessor under accelerated stress testing conditions. Alathon 5046-U was also sold as "Improved Aldyl A." Aldyl A pipes made of Alathon 5046-U continued from 1988 to 1992.

Vintage: 1992-1999

The last improvement in the Alathon resin series occurred in 1992, when DuPont switched from Alathon 5046-U to Alathon 5046-O. Alathon 5046-O offered at least a three-fold improvement in median time to failure over its predecessor.

Table 1: Different Vintages and Resins of Aldyl A

Approximate Years of Manufacture	Alathon Resin	Relative Resistance to Slow Crack Growth
1965-1970	5040	Low
1970-1972	5043, LDIW	Low
1970-1983	5043, non-LDIW	Medium
1983-1988	5046-C	Medium High
1988-1992	5046-U	High
1992-1999	5046-O	Very High

TYPICAL FAILURE MODES

As is true with most plastic pipes, Aldyl A pipes can fail by one of three failure modes:[6]

1. Rapid Crack Propagation;
2. Ductile Rupture;
3. Slow Crack Growth.

Rapid crack propagation is a rare phenomenon, which usually occurs when a pipe is subjected to a rapid external stress, such as from a sharp blow on the pipe. There are on average only a handful of rapid crack propagation failures a year in the entire country. Once a failure occurred, the event would be immediately known by reports of loss of service and there would be little opportunity for the leaking gas to evade detection and to migrate into structures over a prolonged period of time. Ductile rupture is also somewhat rare as it occurs when a pipeline is significantly over-pressurized above its maximum allowable operating pressure due to the malfunction of a pressure regulating device or incorrect operating procedures. The root cause of such overpressure events would be the failure of a pressure regulating device and not a failure of the pipe material itself. Slow crack growth failure is characterized by crack initiation and propagation that occur over many years at relatively low loads below the yield point of the material. Slow crack growth failures are characterized by brittle (slit) fracture surfaces that exhibit very little ductile deformation.

While Aldyl A pipes can also fail due to improper joinings, this would be a problem associated with improper installation rather than a material defect. Likewise, third-party damage would have nothing to do with material failure. For all these reasons, this report elects to focus on the danger associated with slow crack growth, since it disproportionally affects early vintage Aldyl A

[6] Gas Technology Institute, "Plastic Pipe Failure, Risk, and Threat Analysis", Final Report, April 29, 2009.

pipes over other polyethylene gas pipeline materials and this is the mode of failure that has the most potential to cause significant property damage, injuries, or fatalities.

Factors Contributing to Slow Crack Growth on Aldyl A Pipes

Slow crack growth begins when a microscopic defect in the pipe behaves as a stress concentrator when a force is exerted against the defect and enables this defect to grow in response to the stress. Internal pressure is the primary internal stress and field applied loads are sources of external stresses. Typical external stress on plastic pipelines can arise from impingement points due to rocky soil fill; bending or contraction forces arising from differential earth settlement or seismic activity, frost heave, or pipe bending beyond manufacturer's recommended maximum allowable curvature; different expansion/contraction rates of dissimilar materials between a fitting and a pipe body; stress exerted on the pipeline by tree roots; and stresses created when a fitting is fused by heat to a pipe body, where the joining interface may act as a stress intensifier due to geometric discontinuities. Likewise, dents and gouges on the pipe wall caused by installation or excavation damage can also act as external stress intensifiers.

Several Early Warnings

Letters from DuPont

Letter 1, December 17, 1982: Based on several instances of slit fracture on pre-1973 LDIW Aldyl A pipes subjected to rock impingement, DuPont issued the first letter to its Aldyl A customers warning of this danger. The letter urges operators to consider performing more frequent leak surveys on Aldyl A purchased before 1973. The letter also warns against installation procedures which would result in rock impingement on the pipes.

Letter 2, August 25, 1986: Data derived from the Rate Process Method indicating a shortened expected pipe life due to proper squeeze-offs in LDIW Aldyl A pipes prompted DuPont to issue another warning letter in 1986. The letter suggests the use of reinforcement clamps (now commonly referred to as “collars”) to mitigate this hazard. The letter further suggests that collars are effective in preventing slow crack growth at squeeze-off points.

NTSB investigative report

Prompted by the Century Utility Products pipe tragedy in Iowa and other incidents across the country involving plastic pipes that failed by brittle-like cracking through slow crack growth, the National Transportation Safety Board (NTSB) in April, 1998 released a special investigative report on the danger of “**BRITTLE-LIKE CRACKING IN PLASTIC PIPE FOR GAS SERVICE.”**[7,8] Two major conclusions in the report are: 1) much of plastic pipelines manufactured from the 1960s through the early 1980s may be susceptible to brittle-like cracking (by slow crack growth) and 2) manufacturers may have over-rated the strength and resistance to brittle-like cracking of their plastic pipeline products.

PHMSA safety advisories

In response to findings in the NTSB investigative report, the Pipeline and Hazardous Materials Safety Administration (PHMSA) issued a series of safety advisories on the danger of brittle-like cracking on 1960s to 1983 vintage plastic pipes. The first advisory was ADB-99-01, which specifically targeted pipes made by Century Utility Products from a Union Carbide resin. This was followed by ADB-99-02 that more generally applied the advisory to all 1960s to 1983 vintage plastic pipes (DuPont changed from Aldyl A to Improved Aldyl A in 1983). This in turn was followed by ADB-02-07a in 2002 that for the first time specifically identified “Low-ductile inner wall ‘Aldyl A’ piping manufactured by DuPont Company before 1973”, along with PE 3306 pipes and Century pipes, as being susceptible to brittle-like cracking. In 2007, PHMSA released safety advisory ADB-07-01, which added Delrin® polyacetal inserts in DuPont service tees and Celcon® polyacetal caps in Plexco service tees as components susceptible to brittle-like cracking.

[7] NTSB Iowa incident report: DCA-95-MP-001, http://www.ntsb.gov/doclib/reports/1998/PAB9802.pdf

[8] NTSB Special Investigative Report: PB98-917001, NTSB/SIR-98/01, http://www.ntsb.gov/news/events/1998/SIR-98-01/index.html

DESCRIPTION OF UTILITY SYSTEMS

Commission Staff inquired of each natural gas utility in California about how many miles of Aldyl A pipes it has operating in its service territory. When records were available, that information is presented by installation year. While not a perfect overlay, this is the best proxy for vintage of pipeline to diagnose slow crack growth concerns.

Table 2: Current Miles of Aldyl A Mains by Installation Year

Installation Year	PG&E	SoCalGas	SDG&E	SWG (California)	SCE
1965-1972	700	655	188	0	0
1973-1985	3,708	38	6	32	0.3
Unknown manufacturer or installation year	180	7,913	1,435	N/A	N/A

Notes:
1. The year ranges in the table are intended to segregate the early vintage Aldyl A pipes with low resistance to slow crack growth from those that have medium resistance to slow crack growth. The cutoff year of 1985 is slightly arbitrary but is intended to capture most of the Alathon 5043, non-LDIW pipes taking into account the time lag between manufacturing year and installation year.
2. PG&E's mileage of Aldyl A pipes in the table includes both Aldyl A and TR-418 pipes.
3. SoCalGas' mileage of Aldyl A pipes with unknown manufacturer or installation year includes both Aldyl A and other types of PE pipes.

Pacific Gas & Electric (PG&E)

Records from PG&E indicate that between 1965 and 1991, PG&E installed plastic pipes manufactured by DuPont, Nipak, Phillips Driscopipe, Plexco and CSR/PolyPipe. It was only in the 2011 to 2012 timeframe that PG&E began in earnest to determine the extent of its inventory of Aldyl A pipes. It was, and remains so to this day, the practice of PG&E to include installation date and the type of pipe, such as polyethylene vs. steel, but not resin type or pipe manufacturer. This makes precise determination of resin type, manufacturing date, and manufacturer by location and by mileage practically impossible. In the miles of Aldyl A mains table above, the figures are in fact not only for Aldyl A pipes but combined miles of both Aldyl A and TR-418 pipes. In PG&E's case, the unknown number of miles (180 miles in the table) refers to the number of miles of plastic mains that have no recorded entry for installation year. The state of the records is such that it is no longer possible to pinpoint precisely for each location whether a certain underground main is of Aldyl A, TR-418 pipes, or perhaps some other types of PE pipes. This means the actual number of unknown pipes could be much bigger than the 180 miles shown in the table. In an effort to be conservative to capture all Aldyl A pipes, PG&E labeled all PE installations in this period as Aldyl A. Likewise, in order to capture all LDIW Aldyl A pipes, PG&E labelled all installation jobs from 1970 to 1974 as potentially LDIW Aldyl A.

PG&E was also unable to provide records for the number of Aldyl A services connected to steel mains or the number of squeeze-off points without collars. PG&E does not routinely document Aldyl A or LDIW when excavation is performed on an existing pipe. It is also not standard practice to send cutouts to a laboratory for analysis.

PG&E has a dedicated Aldyl A pipeline replacement program that is discussed in detail in its general rate case filing. PG&E uses a pipe segmentation risk ranking methodology where each pipe segment is ranked and prioritized for replacement. With the help of a consultant, PG&E developed a risk ranking program specifically to target its Aldyl A pipeline segments.

Sempra Utilities (SoCalGas and SDG&E)

Due to common ownership by Sempra Utilities, SoCalGas and SDG&E share the same gas operation and maintenance procedures. Sempra's uncertainty with its inventory of Aldyl A pipes mirrors the problem facing PG&E. Sempra has a category of "unknowns" that is far larger than its inventory of known Aldyl A pipes. The unknowns could be Aldyl A, TR-418, or some other types of PE pipes. In other words, the actual inventory of Sempra's earlier vintage Aldyl A pipes could be substantially different from the numbers reported. Sempra has no knowledge of any LDIW pipes because no efforts were made to document LDIW pipes until the 2011 to 2012 timeframe. It is also not customary for Sempra to send cutout sections to laboratories to determine whether a failed segment has LDIW characteristics, nor are reverse bend tests performed in the field. Hence Sempra has no knowledge of any LDIW pipes still within its vast system. Sempra does not have a dedicated program to replace Aldyl A pipes. Sempra also uses a pipe segmentation risk ranking methodology where each pipe segment is ranked and prioritized for replacement. Sempra further uses a normalization methodology to combine the risk ranking for plastic segments with the risk ranking for steel pipes segments to arrive at a combined ranking. Sempra does not have a pipeline replacement program dedicated to Aldyl A pipes.

Southwest Gas (SWG)

Of all SWG's California service territories, Aldyl A exists only in the South Lake Tahoe system that was acquired from Avista Utilities in 2005. According to SWG, it has only a small portion of Aldyl A pipes. In its latest general rate case application (A.12-12-024), SWG proposes to replace all its known Aldyl A pipes by 2018. This paper takes no position on the proposed accelerated Aldyl A replacement plan.

SWG further states that many of the records pertaining to its South Lake Tahoe assets were not transferred to SWG when it acquired the system. Within the category of pipes that SWG considers to be Aldyl A, SWG has been unable to determine the pipe classifications, such as ASTM 2306.[9] It is therefore entirely likely that its actual inventory of Aldyl A pipes could be substantially different from that reported.

SWG does not habitually track resin type, manufacturing date, lot number, or manufacturer. SWG does not use a pipeline segmentation process as do PG&E and Sempra. Instead, SWG manages each potential threat affecting a pipeline separately by using a program called SHRIMP, which stands for Simple, Handy, Risk-based Integrity Management Plan, developed by the American Public Gas Association to rank threats. Aldyl A is included as a threat category in the SHRIMP program.

[9] ASTM stands for American Society for Testing and Materials.

Southern California Edison (SCE)

Although primarily an electric-only company, SCE operates a low pressure propane system on Catalina Island running at less than 6 psig. SCE reports that there have been no failures associated with Aldyl A pipes on Catalina Island. The fact that it is low pressure significantly reduces the occurrence of some of the failure modes where slow crack growth originates from the inside of the pipe. Due to the small size of SCE's Catalina Island system, the problem of uncertainty of the inventory of Aldyl A pipes is much less severe. SCE does not track resin type, manufacturing date, and manufacturer. However, sufficient records exist for SCE to determine that Aldyl A pipes were installed at only one development between 1974 and 1976. Similar to SWG, SCE also uses SHRIMP to aid in its gas distribution integrity management.

Table 3: PHMSA Advisories Warning of Brittle-like Cracking

Year	Advisory	Pipeline Products Targeted in Advisory	Warnings	Key Recommendations
1999	ADB-99-01	Pre-1973 pipes sold by Century Utility Products made from a Union Carbide DHDA 2077 Tan resin	Warns of brittle-like cracking	Recommends identification of all such Century pipes subject to brittle-like cracking. Advisory further advises against repair procedures that rely on pinching (squeeze-off) for isolating sections of Century pipes.
1999	ADB-99-02	Plastic pipes installed between 1960 and the early 1980s	Warns of potential susceptibility to brittle-like cracking. Advisory further warns that rupture testing standards may have overrated the long-term resistance to brittle-like cracking.	Recommends operators to identify all pre-1982 plastic pipe installations, analyze leak histories, and evaluate any conditions that may impose high stresses on the pipe.
2002	ADB-02-07 ADB-02-07a	1. Century products 2. pre-1973 LDIW Aldyl A 3. pipes with PE 3306 designation	Warns of premature brittle-like cracking caused by rock impingement, shear/bending stresses, and squeeze-off	1. Use records to help identify locations of pipelines susceptible to brittle-like cracking. 2. Establish process to identify brittle-like cracking failures, 3. Use consistent format to collect data on system failures. 4. Collect samples of failed polyethylene piping exhibiting brittle-like cracking for possible lab analysis. 5. Record print line information from failed pipes. 6. For systems with no record of the piping material, consider recording print line data when piping is excavated for other reasons.
2007	ADB-07-01	Advisory adds Delrin insert tap tees; and Plexco service tee Celcon (polyacetal) caps to list of products identified in ADB-02-07/ADB-02-07	Not applicable	Not applicable

MEAN-TIME-TO-FAILURE FOR DIFFERENT VINTAGES UNDER DIFFERENT STRESSES

An effective way to measure the resistance of a piece of pipe against failure due to any type of applied stress is to measure its Mean-Time-to-Failure (MTTF) when subjected to such stress. MTTF is a measure of the average time before the first failure under constant application of this stress. MTTF projections due to slow crack growth for the different vintages and formulations of Aldyl A pipes can be obtained from accelerated testing methods. One of the most well-known accelerated testing methods for plastic pipes is the Rate Process Method, which relies on using elevated temperatures and pressures on a population of sufficiently large samples to predict the MTTF of PE pipes in the ground operating at normal temperatures and pressures under various stress factors, such as rock impingement, squeeze-off, bending, and deflection.[10,11,12] For each type of stress under consideration, the Rate Process Method fits the experimental failure points of time, temperature, and pressure to a linear function of the form:

$$\text{Log } t = A + B/T + C \text{ Log } (P)/T$$

Where:

t = slit failure time in hours due to a particular type of stress under consideration

T = temperature of pipe wall in degrees, Kelvin

P = hoop stress, or pressure, psig

A, B, and C are curve fitting constants

The results obtained from the Rate Process Method will be applied to this study. MTTF data for different vintages of Aldyl A pipe and TR-418 pipes obtained from the Rate Process Method

[10] E. F. Palermo, "Rate Process Method as a Practical Approach to a Quality Control Method for Polyethylene Pipe", Eighth Plastic Fuel Gas Pipe Symposium, New Orleans, November, 1983.

[11] E. F. Palermo, "Rate Process Concepts Applied to Hydrostatically Rating Polyethylene Pipe", Ninth Plastic Fuel Gas Pipe Symposium, New Orleans, November, 1985.

[12] E. F. Palermo, "Correlating Aldyl 'A' and Century PE Pipe Rate Process Method Projections With Actual Field Performance", AGA Operations Conference, 2004.

have been furnished by Dr. Gene Palermo of Palermo Plastics Pipe (P^3) Consulting and are summarized below for an illustrative scenario of a 2" O.D. main, operating at 60 psig and 70 ˚F:

Table 4: Projected Mean-Time-To-Failure (years) by Rate Projection Method

Pipe size: 2" O.D. Pressure: 60 psig Temperature: 70 ˚F									
		Confidence Levels							
		50%		**70%**		**90%**		**98%**	
Stress Type	**MTTF**	**Low End**	**High End**	**Low End**	**High End**	**Low End**	**High End**	**Low End**	**High End**
LDIW 5043, indented (rock impingement)	**12**	11	14	10	15	**9**	**16**	8	18
LDIW 5043, squeezed	**21**	16	27	14	31	**11**	**40**	8	53
LDIW 5043, control	144	117	178	104	200	86	243	69	304
non-LDIW 5043, multi saddle	2,291	1,414	3,711	1,087	4,827	691	7,601	404	13,005
non-LDIW 5043, indented (rock impingement)	**71**	44	115	34	149	**22**	**235**	13	404
non-LDIW 5043, control	1,318	1,082	1,604	973	1,784	813	2,135	663	2,618
5046, multi saddle	5,292	3,863	7,250	3,248	8,622	2,395	11,696	1,647	17,005
5046, control	8,094	3,974	16,487	2,701	24,251	1,394	46,990	645	101,506
TR-418 pipe, control	7,474	3,291	16,973	2,106	26,532	973	57,411	391	143,047
TR-418 socket tee, control	250	104	603	64	978	27	2,299	10	6,600

In Table 4, "control" refers to pipe samples that were not subjected to any external stresses such as rock impingement or squeeze-off. The only stress factors acting on the "control" population were the elevated temperature and pressure.

Precise MTTF data obtained from the Rate Process for the earliest vintage of Aldyl A pipes using Alathon 5040 resin are unavailable, but leak rate data from this vintage show comparable failure rates for Alathon 5040 and LDIW Aldyl A pipes.

The primary conclusion from the RPM data as shown in Table 4 is that there are three main waves of failures within the population of all Aldyl A pipes that should be of more immediate concern to an operator. Other waves are expected to occur far enough into the future that they will not be discussed in this paper, on the assumption that all such Aldyl A pipes will have been replaced far in advance of the expected mean times to failure.

Table 5 below shows the pronounced effect of lower operating pressures on the MTTF projections. As the operating pressure is decreased, the MTTF is increased and the confidence interval also widens.

Table 5: Effects of Different Operating Pressures on Projected MTTF (in years)

Pipe size: 2" O.D.								
Temperature: 70 ˚F								
			Confidence Levels					
			50%		70%		90%	
Stress Type	**Pressure**	**MTTF**	**Low End**	**High End**	**Low End**	**High End**	**Low End**	**High End**
LDIW 5043, indented (rock impingement)	40 psig	**20**	18	23	17	25	**15**	**28**
	50 psig	**15**	14	17	13	19	**12**	**21**
	60 psig	**12**	11	14	10	15	**9**	**16**
LDIW 5043, squeezed	40 psig	**50**	37	69	31	82	**23**	**110**
	50 psig	**31**	23	41	20	48	**15**	**63**
	60 psig	**21**	16	27	14	31	**11**	**40**
non-LDIW 5043, indented (rock impingement)	40 psig	**115**	67	195	50	261	**30**	**432**
	50 psig	**88**	54	146	41	192	**25**	**308**
	60 psig	**71**	44	115	34	149	**22**	**235**

With the exception of SCE's low-pressure system on Catalina Island, all operators have a significant percentage of polyethylene pipelines operating at different pressures according to the approximate profile below:

Table 6: Approximate Operating Pressure Profiles of Polyethylene Pipelines

Operating Pressure	PG&E	Sempra	SWG (California)	SCE
<7	n/a	n/a	0%	100%
<40	6%	7%	3%	0%
40 to 49	15%	22%	63%	0%
50 to 54	36%	30%	0%	0%
55 to 60	43%	41%	34%	0%
Total	100%	100%	100%	100%

Note: Pressure profiles for PG&E and Sempra were derived from historical gas incidents reported to the CPUC and are only representative of their current actual pressure profiles. The actual pressure profiles will differ slightly from these figures.

Table 7 below is obtained by combining Tables 1, 4, and 5 and by recognizing the maximum 3-year difference between manufacturing date and installation date:

Table 7: Projected Year in which Failure Would Occur for Different Pressures

Pipe size: 2" O.D.								
Temperature: 70 ˚F			Confidence Levels					
			50%		70%		90%	
Stress Type	Pressure	Peak Year	Beginning Year	End Year	Beginning Year	End Year	Beginning Year	End Year
LDIW 5043, indented (rock impingement)	40 psig	1993	1988	1998	1987	2000	1985	2003
	50 psig	1988	1984	1992	1983	1994	1982	1996
	60 psig	1985	1981	1989	1980	1990	1979	1991
LDIW 5043, squeezed	40 psig	2023	2007	2055	2001	2068	1993	2096
	50 psig	2003	1993	2027	1990	2034	1985	2049
	60 psig	1993	1986	2013	1984	2017	1981	2026
non-LDIW 5043, indented (rock impingement)	40 psig	2093	2037	2181	2020	2247	2000	2418
	50 psig	2067	2024	2132	2011	2178	1995	2294
	60 psig	2050	2014	2101	2004	2135	1992	2221

For the illustrative case of 2” O.D. pipe, operating at 60 psig and 70 ˚F, the first wave of pipe failure arises from rock impingement on LDIW Aldyl A pipes made of Alathon 5043 resin. Recall that LDIW Aldyl A pipes were manufactured from 1970 to 1972 and installed from 1970 to 1975. The installation date range differs from the manufacture date range due to time lag introduced by product delivery and storage of inventory at an operator’s yard before the product was installed in the ground. There was typically up to a one year time lag due to delivery and up to two years between receipt of delivery and installation in the ground. Since the operators in this study only tracked installation dates and did not record the manufacture dates of their batches of pipelines, it is logical to add three years to the vintages in order to arrive at some conservative interval to bracket the at-risk pipelines. The MTTF of this first wave is 12 years at 60 psig and 70 ˚F with a 90th percentile range for a failure event to occur between of 9 years to 16 years. In other words, for pipelines that would eventually fail due to rock impingement, there is a 90% probability that the failure would occur between 9 years and 16 years after initiation of the stress due to rock impingement, with average time to failure of 12 years. We caution that the previous statement should not be misinterpreted to imply that 90% of all LDIW Aldyl A pipe made of Alathon 5043 resin that are subjected to rock impingement will fail between 9 years and 16 years. The correct interpretation should be that of the very small sub-population of all LDIW Aldyl A pipes made of Alathon 5043 resin that would eventually fail due to rock impingement, 90% of the failures would occur between 9 years and 16 years at 60 psig and 70 ˚F. This distinction is important because not all Aldyl A pipes are subjected to rock impingement and, more importantly, a rock impingement has to be severe enough and be fortuitous enough to apply stress on a microscopic defect on the brittle inner wall to lead to initiation of slow crack growth in order for a failure to eventually occur. Since the last of this vintage of LDIW Aldyl A pipes was installed in around 1975 (1972 manufacturing date + three years due to depletion of inventory), the 90th percentile to affect this wave occurred between 1979 and 1991, with a peak at around 1985. Except for some short isolated sections of the population where the soil might have been disturbed again due to leak repairs, the wave of leaks should be substantially behind us. Even in cases where the soil might have been freshly re-disturbed, due to new excavation activity, the type of fill used would be expected to conform to new specifications to minimize stress due to rock impingement. To put it differently, if a LDIW Aldyl A pipe were subjected to rock impingement, initiation of a microscopic defect leading to slow crack growth and ultimate pipe failure would either not occur at all or, if it did, it would have likely occurred years ago, with the vast majority of such cases occurring before 1991. From a modeling standpoint for this illustrative scenario of a 2" O.D. main, operating at 60 psig and 70 ˚F, there should be few new cases of leaks due to slow crack growth caused by rock impingement in LDIW Aldyl A pipe. However, as Table 4 and Table 6 show, lower operating pressure can delay the onset of this wave as well as other waves.

Likewise, the second wave of failures peaking at 21 years for the illustrative scenario arises from stress concentration due to squeeze-off operations on the LDIW subpopulation of Aldyl A made of Alathon 5043 resin. Squeeze-off operations are typically employed to perform leak repairs. Of the three waves, this wave is potentially the most long-lived because the clock starts not from the time the pipe is laid in the ground, but at any time a squeeze-off is applied after installation. Each time a leak is repaired, squeeze-off points are introduced and the clock starts counting down to the 90% confidence level of time to failure between 11 years and 40 years after the squeeze-off operation. An important moderating factor affecting this wave is that slow crack growth arising from squeeze-off applies only to the very tiny fraction of LDIW Aldyl A pipelines that were ever subjected to a squeeze-off operation and not to all LDIW Aldyl A pipes in general, as is the case with rock impingement.

As a result of the 1986 letter from DuPont, operators began to install reinforcement clamps, termed a "collar," over squeeze-off points in an attempt to restore the sections to a more circular shape in order to lessen the concentration of stresses at the squeezed points. Collars were also effective in lessening the chances of a squeeze-off point from failing due to slow crack growth. Since collars were not generally used on squeeze-off points at least prior to 1987, perhaps even later, it is reasonable to conclude that all the pre-1987 squeeze-off points are at risk of potential failure. At the 70% confidence level of 14 to 31 years, the upper range will end in 2017. At the 90% confidence interval of 11 years to 40 years, this wave will not end until 2026.

This second wave could potentially be even longer depending on when an operator began to adopt the use of collars as a mandatory procedure after a squeeze-off operation. The only certain inference one can reasonably draw is that there is a large legacy of pre-1987 leak repairs where squeeze-offs were performed without the use of collars that are now at risk of failure, although these are now at the tail end of this wave. Again, a lower operating pressure could significantly delay the onset of this second wave.

It should be noted that stress due to rock impingement occurs far more frequently than from squeeze-offs. Each contact point with a sharp rock is a potential initiation point, whereas a pipe segment has to have been squeezed to face the risk of failure due to squeeze-off.

Lastly, the third wave of failures at a MTTF of 71 years for the illustrative scenario arises from rock impingement on Aldyl A pipes made of Alathon 5043 resin that are free of LDIW characteristics. These were pipes that were manufactured from 1970 to 1983 and were generally installed from 1970 to 1986. The 90% confidence interval of failure times ranges from 22 years to 235 years. This wave began to rise slowly in 1992, steadily climbing to a plateau around 2012. This plateau is the extended weak peak for this wave and it will remain sustained close to this weak peak for close to the next hundred years due to the very large standard deviation of this wave.

In this section we only highlighted pipe failures due to rock impingement and squeeze-off, but earth settlement can also lead to slow crack growth. In fact excessive earth loading has resulted in almost 13% of all Aldyl A pipe and fittings failures according to anonymous data collected by the Plastic Pipe Data Collection Committee of the American Gas Association (AGA).[13] The AGA data further show that failures due to fittings account for almost 50% of all leaks on Aldyl A pipelines. Aldyl A fittings susceptible to failure include Delrin® polyacetal inserts in DuPont service Tees, Aldyl A Tees, Aldyl A saddles, and Aldyl A couplings.

With accurate knowledge of Aldyl A pipeline assets, including information on the amount of pipes installed by year and by manufacturing vintage, it is possible to construct mathematical models to predict the number of future failures by year due to each mechanism for each respective vintage of Aldyl A pipe by using the relevant MTTF data. Doing so would require making many simplifying assumptions and the need to blend these assumptions with actual operator-specific experience. This is a level of complexity we will not get into in this paper, particularly in light of the great uncertainties surrounding the quality of data provided by the operators. Instead, we will put the onus on the operators on how to prudently deal with data uncertainties caused by poor material traceability and poor asset knowledge in formulating a credible and cost effective risk management strategy.

[13] Plastic Piping Data Collection Initiative Status Report, March 27, 2013, Appendix D.

EXTRA SCRUTINY ON EARLY VINTAGE ALDYL A IS WARRANTED

We are mindful that proper risk management should examine all identified hazards in concert and deal with the hazards in relation to one another. Given the unique combination of factors facing the challenge of managing the risk presented by Aldyl A pipes, the extra scrutiny accorded older Aldyl A pipes is warranted.

First, slow crack growth on Aldyl A pipes fundamentally poses a high level of risk due to the abrupt nature of leaks created by this mode of failure. Unfortunately, more frequent leak surveys do not sufficiently mitigate the risk posed by slow crack growth on early vintage Aldyl A pipes to the point where this risk will become manageable.

When a PE pipe fails by slow crack growth, the crack can propagate either from the inside of a pipe to the outside or from the outside of the pipe and propagate to the inside, depending on the source of stress and the failure mechanism. In the 1996 San Juan incident, the crack propagated from the external side to the internal side. This crack was caused by bending stress acting on a stress intensification area created by the notched area between the coupling and the pipe body (Figure 1 on Page 4). The NTSB investigation revealed that the slit on the external side of this crack (entry side) measured only 1/4" in length, but by the time the crack propagated to the internal side (exit side), the crack had fanned out to create an exit measuring approximately 1" in length. This fanning characteristic of a small crack entry broadening significantly to a long exit crack is typical of slow crack growth propagation on PE pipes and explains much of the potential danger associated with all PE pipes with a weak resistance to slow crack growth and not just early vintage Aldyl A pipes.

Until a crack breaches the opposite side of a pipe wall, there will be no indication of a slowly developing crack. The crack might have taken many years to propagate from the initiation side to the exit side, but when this crack finally breaches the exit surface it will develop into a long exit crack in a very short time. A sufficiently long crack will have a large enough cross-section area to allow gas to escape with a sufficient flow rate to migrate into structures and accumulate dangerously, but the flow rate will not be so high, as in a complete pipe rupture, for residents and bystanders to reliably detect the leaking gas by their sense of smell. The smaller entry crack limits the throughput of gas escaping through a breached crack, but even a small ¼" long entry crack, as that found on the pipe in the San Juan incident, was sufficient to produce a leak rate of 102 cubic feet an hour.[14] This leak rate was sufficiently small so as to evade timely and reliable notice by residents and bystanders, but sufficiently large to migrate underground and accumulate in the structure and cause the explosion. The abruptness of the failure from no flow to sufficient flow to cause undetected danger simply cannot be reliably caught in a timely manner by even annual leak surveys. This is what makes PE pipes with low resistance to slow crack growth so potentially dangerous and early vintage Aldyl A pipes fall in this category.

Second, California Gas operators have poor historical documentation of resin type, manufacturing date, and manufacturer, and other relevant pipeline asset information to aid in material traceability. It was common practice, and in fact remaining so to this day, for operators to document only installation dates and types of pipe material (i.e. polyethylene vs. steel, etc.), without specifying the manufacturer, trade name, resin type, and other relevant information to aid in material traceability and enhanced asset knowledge. For example, records of California operators in this study would only indicate an installation is of polyethylene pipes, but not whether it is Aldyl A PE pipes. In some cases operators rely on "tribal knowledge" to keep information alive, but this method is short-term since key personnel routinely retire.

A risk management program is only as effective as the accuracy and specificity of the input data into the program. From 1965 to the mid-1980s, California gas operators installed both Aldyl A PE pipes and other types of PE pipes. With poor asset knowledge of whether a particular installation during this period was of Aldyl A or some other PE pipes, a conservative approach is to assume all PE pipe installations during certain years are the more leak-prone Aldyl A pipes.

[14] Per NTSB report.

This conservative approach, while sound from a risk assessment point of view, has tremendous cost implications since it could unnecessarily force early retirement of the less leak-prone non-Aldyl A PE pipes.

Additionally, mathematical models based on Aldyl A leak rate data would yield unreliable results due to commingling of the mileage and leak data between Aldyl A and non-Aldyl A pipes.

DISCUSSION

The danger associated with older vintage Aldyl A pipes highlights the need for better records for material traceability and asset knowledge. Asset knowledge and material traceability were issues dating from the days of paper-based records and will remain so when these paper records are transferred into computerized format. All the operators examined by us have a sizable quantity of pipes with unknown manufacturing dates, unknown resin types, unknown lot numbers, or even unknown manufacturer sources. Without more robust material traceability to know with a great degree of certainty what assets are in the ground, risk assessment and risk mitigation strategies will be at best enormously expensive and at worst ineffective. Even going forward, some of these operators still have no plans to collect these types of information as they are not required to do so by pipeline regulations.

Operators should adopt opportunistic identification as a standard practice to determine whether an exposed pipe segment is of Aldyl A or some other PE pipes. If the pipe is Aldyl A efforts should be made to determine whether it is of LDIW type by a simple reverse bend test in the field whenever sections are cut out. On Aldyl A pipes, operators should also use opportunistic identification to record stress intensifiers, including squeeze-off points without collars and rocky soil fills that may cause rock impingent failures, as well as others. At present, California gas operators do not rely on opportunistic identification as a standard practice to help verify their inventory of Aldyl A pipes, nor do they identify the type of fill that might point to potential rock impingement issues.

Provided operators have good knowledge of their inventory of Aldyl A pipes, the hazard associated with Aldyl A is not necessarily unmanageable, but where operators have poor knowledge of their physical assets, then all the mitigation strategies become an unpredictable venture. Even in the best of circumstances when the operators have good knowledge of their Aldyl A assets, they are still beset by uncertainty arising from the difference between manufacturing date and installation date. This is a form of material traceability and asset knowledge problem. It is incredibly shortsighted for a gas operator to ignore the potential costs and consequences of poor asset knowledge and poor material traceability.

Operators did not always act on PHMSA's safety advisories in a timely manner. Operators had certain knowledge of the danger of premature failure associated with pre-1973 LDIW Aldyl A no later than 2002, when PHMSA released safety advisory ADB-02-07 and specifically mentioned pre-1973 Aldyl A. In fact, this knowledge occurred even earlier, when warning letters about pre-1973 LDIW Aldyl A were sent out by DuPont to the operators in 1982 and 1986, but the PHMSA advisory contained the strongest and clearest warning yet and so we will use 2002 as the base year when operators had explicit knowledge of the elevated danger and should have acted accordingly. Yet, the California operators in this study did not make a serious effort to document the location of Aldyl A pipes, in particular pre-1973 Aldyl A with LDIW, until being essentially compelled to do so by the implementation of PHMSA's gas Distribution Integrity Management Program (DIMP) in 2012. Sempra Utilities, for example, has no knowledge of the existence of any pre-1973 Aldyl A pipes with LDIW characteristics in its entire system even to this day because it was only in 2011/2012 that this operator began to collect information on LDIW pipes in its system. PG&E also has no standard procedures in place to routinely collect such information.

It is confounding that operators did not collect such information even if they were not required by law, when PHMSA safety advisories clearly demonstrated a need for prudent action a full decade prior. Granted that these were but advisories and the adoption of the recommended actions contained therein were voluntary, the potential danger associated with early vintage

Aldyl A pipes, as highlighted by the 1996 San Juan tragedy, made a compelling case for prompt action.

Due to low resistance to slow crack growth of earlier vintage Aldyl A pipes and the abrupt failure nature of slow crack growth, planned replacement rates may not be sufficient to mitigate risk nor can more frequent leak surveys. As shown in the MTTF section in this paper and Table 7, failure rates on non-LDIW pre-1983 Aldyl A will begin to rise in the coming decades, depending on actual operating pressure, temperature, and other pipeline specific variables, based on data obtained from the Rate Projection Method.

The danger associated with slow crack growth on Aldyl A is that although the failures develop slowly, when they do fail, they fail much more abruptly and rapidly than underground leaks on steel distribution pipes. Instead of small pin-hole leaks developing slowly over a number of years, as is typical of steel pipes, leaks on Aldyl A are far more likely to be of a serious nature much more quickly. The 1996 San Juan incident and the two 2011 California incidents are good examples of this abrupt failure characteristic.

Pipeline safety regulations only require pipelines in distribution systems to be leak surveyed at annual intervals in business districts and at 5 years intervals in non-business districts. The abrupt failure nature of Aldyl A by slow crack growth means that leaks can develop undetected quickly between even annual leak survey intervals and migrate underground into structures and cause explosions.

SUMMARY OF FINDINGS

1. All early vintage Aldyl A pipes have low resistance to slow crack growth.

2. Aldyl A pipes with LDIW characteristics have both a significantly shortened crack initiation time and a low resistance to slow crack growth.

3. There is no non-destructive test in the field that can distinguish LDIW Aldyl A pipes from standard Aldyl A pipes.

4. California operators typically did not record the resin type and manufacturer of PE pipeline installation.

5. California gas operators typically recorded only the installation date and not the manufacturing date of the PE pipes.

6. Since historical installation records did not capture the relevant information, the mileage and location of Aldyl A pipes and LDIW Aldyl A pipes cannot be reliably determined after installation without performing excavation and possibly destructive testing.

7. California gas operators do not have a standard practice to use opportunistic identification when pipelines are exposed to capture relevant information that would aid in the identification of Aldyl A pipes and any stress intensifiers acting on the Aldyl A pipes.

8. Lack of specific and accurate record keeping distinguishing Aldyl A pipes from other assets highlights the need for better records for material traceability and asset knowledge. California gas operators have a sizable quantity of pipes with unknown manufacturing dates, unknown resin types, unknown lot numbers and even unknown manufacturer sources.

9. Without more robust material traceability to know with a great degree of certainty what assets are in the ground, risk assessment and risk mitigation strategies will be ineffective and expensive.

10. DuPont provided warning letters in 1982 and 1986 regarding pre-1973 LDIW Aldyl A pipes.

11. Initial PHMSA advisories were issued as early as 2002, providing certain knowledge of the risks of premature failure on pre-1973 LDIW Aldyl A pipes.

12. California gas operators have not acted on PHMSA safety warnings in a timely fashion. No meaningful action to identify inventory of Aldyl A pipes was undertaken until 2011/2012 when PHMSA's gas Distribution Integrity Management rules went into effect.

13. Depending on the different stress factors created by an operator's unique operating conditions, there could be different waves of failures unique to the operator in the oncoming decades. It is highly probable that the waves will occur sooner and with more intensity if the pipe is early vintage Aldyl A.

14. Some important pipeline data were not transferred by Avista Utilities to Southwest Gas when the South Lake Tahoe system was purchased from Avista Utilities.

RECOMMENDATIONS

This paper has highlighted the potential danger associated with early vintage Aldyl A pipes. It would be an undesirable outcome, however, for an operator to rely on this paper's determination of early vintage Aldyl A pipelines to be a potential major pipeline hazard as sole basis for wholesale removal of early vintage Aldyl A pipes from their systems. A properly executed comprehensive pipeline risk management program should take into account all identified threats affecting pipeline safety in combination, rather than to treat each threat in isolation, in order to arrive at the best allocation of utility resources needed to minimize the combined risks created by the threats in a cost effective manner. The potential hazards with early vintage Aldyl A pipes are operator specific, depending on the stress factors put on the pipes by the operators. Having highlighted the potential danger associated with early vintage Aldyl A pipes, we defer the mitigation of this potential hazard and the consideration on the scope and pace of any replacement program to the operators' judgment, since pipeline replacement programs are more suitably dealt with in the larger context of a general rate case or equivalent proceeding. We instead make recommendations to address impediments we identified which collectively can prevent our jurisdictional operators from effectively managing the potential danger associated with early vintage Aldyl A pipelines.

Whereas gas safety regulations are generally viewed as minimum compliance standards, our efforts in this study to recognize potential safety concerns are unencumbered by existing or prior requirements in federal and state gas safety regulations. When strong recommendations are called for, our recommendations may exceed these minimum requirements and, in this spirit, we make the following safety recommendations:

1. **Operators should develop a more robust asset knowledge and material traceability program on their gas distribution assets**. This is consistent with the requirements and intent of PHMSA's DIMP regulations. Not knowing the system directly contradicts the spirit, if not the letter, of the DIMP regulations. Following the San Bruno tragedy, PG&E has made great strides

in this area on the gas transmission side, but all operators are still deficient on material traceability and asset knowledge on the gas distribution side.

2**. Operators should develop a strategy for better integrating supply chain information (e.g. resin type, manufacturing date, lot number, and other manufacturing data that are typically available during the purchase of materials).**

3. **Where feasible, operators should make use of opportunistic identification to determine whether an exposed pipe segment is of Aldyl A or some other materials and, if it is Aldyl A, whether the pipe has LDIW characteristics whenever sections are cut out.**

4. **Operators should react expeditiously to manufacturer warnings and PHMSA safety advisories.**

5. **Operators should re-examine their risk assessment and mitigation strategies to ensure they will be replacing the at-risk pipes at a sufficient rate to mitigate the risk associated with LDIW Aldyl A pipes dues to squeeze-offs and to pre-1983 non-LDIW pipes due to rock impingement.**

6. **Operators should, if not already doing so, explicitly consider the impacts of at-risk Aldyl A pipes in their next risk assessment and mitigation strategies provided to the Commission.**

7. **When acquiring systems, operators should ensure relevant pipeline records are transferred as a condition for final acquisition of a system.**

Within 60 calendar days of this report, Commission staff is requesting that the gas operators identified in this study submit a proposal to the director of the Safety and Enforcement Division and the Executive Director on how to address these safety recommendations. The proposal should also describe what actions the operator will take to address the following questions:

1. What actions will the operator take to remedy the historical deficiencies in asset knowledge with respect to Aldyl A pipes highlighted in this paper?

2. What actions will the operator take to address the different waves of expected failures on Aldyl A pipes due to the different stress intensifiers acting on the different vintages of pipes given the historical deficiencies in asset knowledge? The operators should not limit themselves to only the intensifiers we highlighted in this report.

3. In what forum (e.g. a general rate case or a separate application) will each operator intend to address the mitigation of the potential hazards posed by early vintage Aldyl A pipes?

Commission staff also requests that the operators concurrently serve their proposals to all parties in their respective outstanding general rate case proceedings and the gas safety rulemaking proceeding, R.11-02-019.

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