Acceptable Methods for Alternative Sampling to Meet the Requirements of 192.607

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Abstract

With the passage of §192.607 and PHMSA's subsequent responses in FAQ's 21 and 22, ILI is an approved method for measuring properties and delineating pipe into populations with similar characteristics. In cases where material properties remain unknown, ILI populations can be leveraged to optimize decision making and test locations to close out material property verification. The process must achieve the required confidence without necessarily having to test one sample per mile, as defined in regulation. §192.607(e)(5) that states an alternative statistical sampling approach can be used if it can "achieve at least a 95% confidence level that material properties used in the operation and maintenance of the pipeline are valid." This paper will provide detail on two alternative sampling approaches that received no-objection notifications from PHMSA. The approaches are based on a combination of ILI and testing. The efficacy of this approach will be demonstrated using the assessment program performed by Dow Chemical to define the status of existing material properties and produce a plan to close out unknowns on their 8" line segment. The discussion will provide specifics of the approach used by Dow, including the scope of documentation required to support its implementation and acceptance by the regulator.

1. Introduction

As per United States Code of Federal Regulation Part §192.607, material properties and attributes for all gas transmission pipelines must be traceable, verifiable, and complete (TVC). When records alone do not satisfy TVC criteria (non-TVC), one path for attaining TVC status is to define populations of similar pipe and perform testing at a mandated frequency of one test per mile. However, the one test per mile approach is not always the most practical method to verify material properties. §192.607(e)(5) allows operators to elect an alternative sampling approach if it achieves at least a 95% confidence level that the material properties are valid.

Alternative sampling approaches are effective when they are based on accurately defined pipe populations that are delineated using the following material properties and attributes: outside diameter (OD), wall thickness (WT), strength, pipe type, and joint length. In-line inspection (ILI) technologies measure these properties, and pipes are assigned into populations based on similar material characteristics. A neighboring analysis is conducted on each pipe joint that provides sufficient confidence that pipes have been assigned to the correct population. Any outliers within datasets are identified and assessed individually, and if necessary, separated into a different population. Since this process defines pipe populations based on shared material properties, supported by ILI data, any material testing on a pipe in each population is directly representative of the entire population.

When populations have been defined and available records are aligned to the populations, candidates for alternative sampling can be selected. This paper will explain the two alternative sampling approaches, developed by ROSEN, that have both received no objection from PHMSA confirming they are acceptable for implementation. Examples from an operational line segment, owned by Dow, are presented to explain the effectiveness and benefits of their application.

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2. Methods and justification

Since populations are defined as groups of pipes with similar material characteristics, the measurements from ILI for each pipe can be used to assign populations based on OD, WT, strength (both yield strength and ultimate strength), seam type and joint length. These properties are critical because they are the variables used in Barlow's equation for calculating the design pressure and MAOP of a line segment. When pipe is manufactured from steel, which is made in batches, the strength of all pipes will exhibit a normal distribution that conforms to the targeted grade of the steel. ILI strength measurements reflect these strength distributions within a pipeline, which is valuable for delineating populations since pipes could have similar characteristics, but individual pipes in a pipeline can have a large variance in strength. Any strength outliers or rogue pipes can be accounted for and separated into a different population if they do not fit the characteristics of other populations. If strength is not considered, pipes with the same wall thickness and other properties could be incorrectly included in the same population even though the strength is significantly different. Performing ILI to gather strength measurements is essential for accurately defining populations and maintaining proper integrity management.

Extensive research and testing have been completed on the technology to define the specification of the tool and ensure that it continues to operate within its designated tolerance. Validating tool performance is important for justifying the use of alternative sampling since regulation in 192.607(e)(5) requires at least a 95% confidence in valid material properties. Further, proving validity at a 95% confidence level is only possible with accurate populations that have been delineated using multiple ILI datasets, including strength.

Regardless of how material properties are verified, accurately defined populations are essential to ensure all material properties are captured within a pipeline. Since ILI measures the material properties and identifies the population boundaries, the amount of testing can be significantly reduced because tests for multiple populations can be performed in one excavation at population junctions. Furthermore, because ILI measures the strength of every pipe, this gives insight to the different strength distributions and their location along the pipeline, as shown in Figure 1. This leads to an increased level of certainty for the grades assigned to each population.

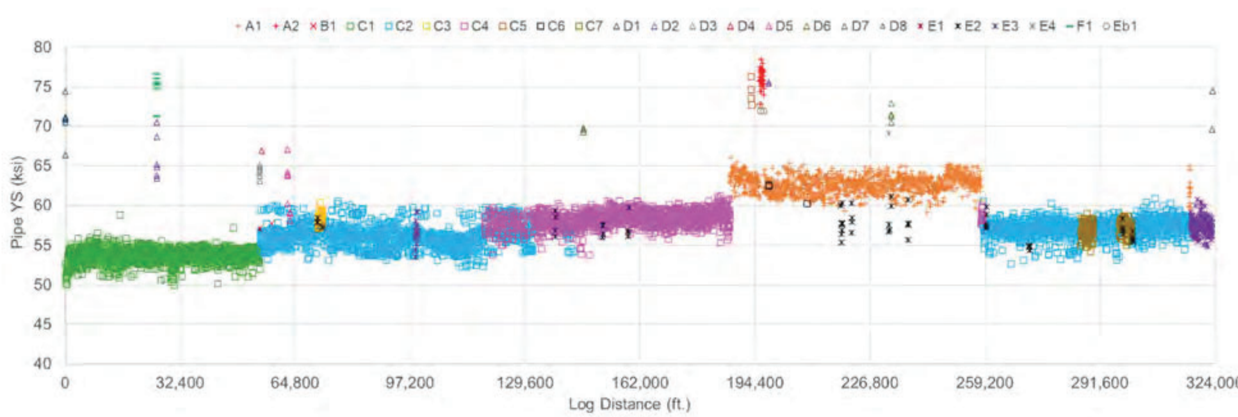

Figure 1. Population Strength Distributions Throughout a Pipeline (populations with the same letter are the same WT and the number designates the sub-populations within each nominal WT)

Using documentation and a random one per mile sampling approach, without ILI, is not an effective approach for correctly characterizing the properties and attributes. Without ILI measurements on each pipe, there is no insight on the thousands of other pipes that are not directly tested. It is unlikely that outliers or rogue pipes will be identified and tested using the random test selection of one per mile as there is less than a one percent chance of a 40-foot pipe joint being tested in a one-mile segment.

2.1 Alternative sampling approach: Method A

The foundation of the Method A alternative sampling approach is ILI strength measurements that represent manufactured strength distributions of a pipe population. These distributions give statistical confidence that values from a reduced amount of testing are representative of an entire population. The methodology analyzes test results (destructive or non-destructive) using statistics of a normal distribution to calculate a lower bound limit. After the lower bound limit is calculated, the next lowest pipe grade is assigned to the population. The test data mean ($\bar{x}$) is the average strength of the tested pipes and the standard deviation (S) describes the variability around the mean. Figure 2 below describes the mean and standard deviation of a normal distribution.

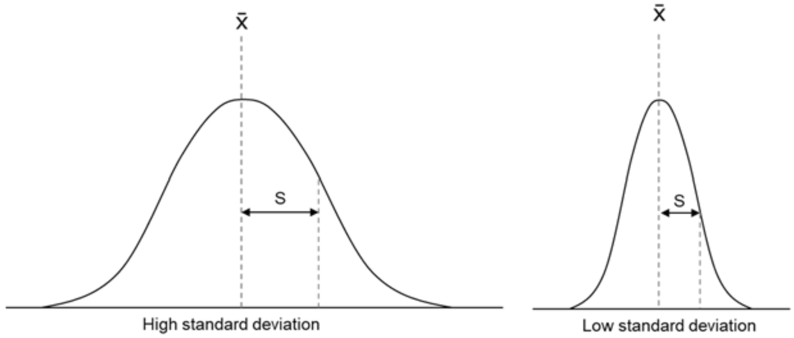

Figure 2. Normal Distribution with Mean and Standard Deviation Annotated

When the mean and standard deviation are known, a lower bound strength limit can be calculated using the desired confidence level of a normal distribution. The main concern when testing strength is pipes with strengths that are lower than what is expected or required for the operational conditions of the line segment. Therefore, the strength measurements collected are analyzed using probabilities of a one-sided normal distribution to account for any lower strength outliers within a population. The lower bound 95% confidence level using one-sided probabilities is defined as 1.645 standard deviations below the mean, as shown in Figure 3. Since this is a one-sided confidence level, there is a 95% probability that any untested pipe would be greater than this value and a 5% chance that further testing would result in values lower than this limit.

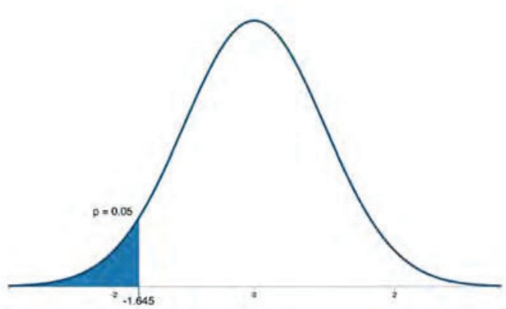

Figure 3. 95% Confidence Limit of a One-Sided Normal Distribution

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The lower bound 95% confidence limit for YS and UTS is calculated using equation (1). This equation is taken from the ASME CRTD Vol. 91 [1] paper, which illustrates how to use measurements on a sample of pipe to determine the lower bound yield strength for a population. As explained in CRTD Vol. 91, the subtraction factor is determined by the desired confidence level, sample size and targeted percentile. When ILI has been used to measure material properties and define populations, and testing has occurred destructively or non-destructively, a subtraction factor of 1.645 is used to achieve a 95% confidence level.

$$\text{95\% lower bound YS (or UTS)} = \bar{x} - (S \cdot SF) \quad (1)$$

Where,
$\bar{x}$ = mean
S = standard deviation
SF = subtraction factor

When considering test data from tensile testing (destructive testing), no measurement error is considered since this value is regarded as the true strength of a material. Measurement error must be considered for non-destructive testing as required by §192.607(d). The measurement error is dependent on the non-destructive method used and varies based on instrument specifications. The resulting value calculated using equation (1) is used directly to assign a grade to the population. For example, if the lower bound value is 54.2 ksi, the best fit grade for the population can be assigned as X52.

2.1.1 Minimum number of tests required

Because the number of tests required is based on test results, the number is not always known before testing begins. Dow decided to include a set of criteria that defined a specific number of minimum tests within their 192.18 submissions for alternative sampling as a starting point. The intent was to define a clear path on how the number of tests would be determined and what would be done if those tests did not give the expected result.

When using this alternative approach, the minimum number of tests required for populations greater than 1 mile in cumulative length is two, as at least two tests are required to complete a comparative statistical analysis using equation (1). The amount of testing required is based on the cumulative length of the population, along with any available documentation traced to the population. A percentage of the cumulative length is tested based on the strength of available documentation. The number of tests and associated criteria is detailed in sections 2.1.2 and 2.1.3.

2.1.2 When ILI and non-TVC documentation is available

When non-TVC documentation is available, and ILI corroborates the grade in documents, the intent is to confirm that the non-TVC grade is correct. For this scenario, 25% of the population's cumulative length in miles is tested, rounded up to the nearest integer. For example, if a population is 27.7 miles long, it would be rounded up to 28 miles and the initial plan would be to perform seven tests. The test results are analyzed using equation (1) to determine the lower bound 95% confidence limit for strength. If the lower bound limit is the same or higher than the expected grade, testing is complete. The grade stated in documentation and corroborated by ILI and testing is confirmed as TVC for that population. If the 95% lower bound from testing is below the required grade, further testing is required at the same frequency as stated in Section 2.1.3.

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2.1.3 When no documentation is available

When no documentation is available, the intent is to define grade through testing. In this scenario, 50% of the population's cumulative length in miles, rounded up to the nearest integer, is tested. For example, if a population is 27.7 miles long, it would be rounded up to 28 miles and the initial plan would be to perform 14 tests. The test results are analyzed using equation (1) to determine the lower bound 95% confidence limit for strength. If the lower bound limit is consistent with the ILI grade, then testing is complete. The grade from testing, corroborated by ILI, is considered TVC. If the results from testing are not corroborated by ILI, further testing is required at a frequency of one test per mile.

2.1.4 Determining grade when testing does not meet the required grade

In scenarios where the lower bound grade from the options above or the one per mile approach is lower than expected, further analysis is required. The first step is to check if the resulting grade is sufficient for the MAOP of the pipeline. This is an important step. It could be that the expected grade is X65, and verification can only confirm X60. This is a discrepancy, but it does not necessarily mean that the verified grade of X60 is an issue, providing it is sufficient for the MAOP. Using a reverse calculation of Barlow's equation shown in equation (2), the minimum required strength for a specific MAOP can be calculated. The material properties of the population and associated factors must be known to determine the minimum strength required. The resulting output of equation (2) is used to assign the next lowest API 5L best-fit grade.

$$S = P \cdot D / (2t \cdot F \cdot E \cdot T) \qquad (2)$$

Where,
P = MAOP (ksi)
S = Minimum Required SMYS (ksi)
t = wall thickness (inches)
D = diameter (inches)
F = class location design factor
E = joint factor (dependent on seam type)
T = temperature factor

The grade from testing can be compared against the grade determined by equation (2), and if it is higher, the grade from testing is acceptable for operation at the MAOP even if it is lower than expected. If the grade from testing is lower than that required for the MAOP, an expanded sampling procedure can be leveraged to investigate the grade of the population further, as required in regulation.

2.2 Alternative sampling approach: Method B

In some cases, non-TVC populations are in non-accessible locations that prevents testing. Other populations have a limited number of pipes where testing would be possible in terms of location and accessibility, but unlikely in terms of opportunity. In these cases, the properties of the populations would remain unverified over the long-term. As an alternative, validated ILI data can now be used to define a grade and other material properties for the population.

The pre-requisite for this approach is completion of an API 1163 Level 2 ILI system validation. The validation must cover the diameter, specific wall thickness, grade, and pipe type (i.e., seamless, longitudinally welded, helically welded) of the population to which this approach is being applied.

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The validation must confirm that the ILI performance specification has been met. An example of an API 1163 Level 2 unity plot is shown in Figure 4 below. In this example, the unity plot can be used to support the use of ILI for populations of longitudinally welded pipe, with a grade range of Grade B to X65 and wall thickness of 0.250". If data was available for other thicknesses, then it could be applied across populations with that thickness.

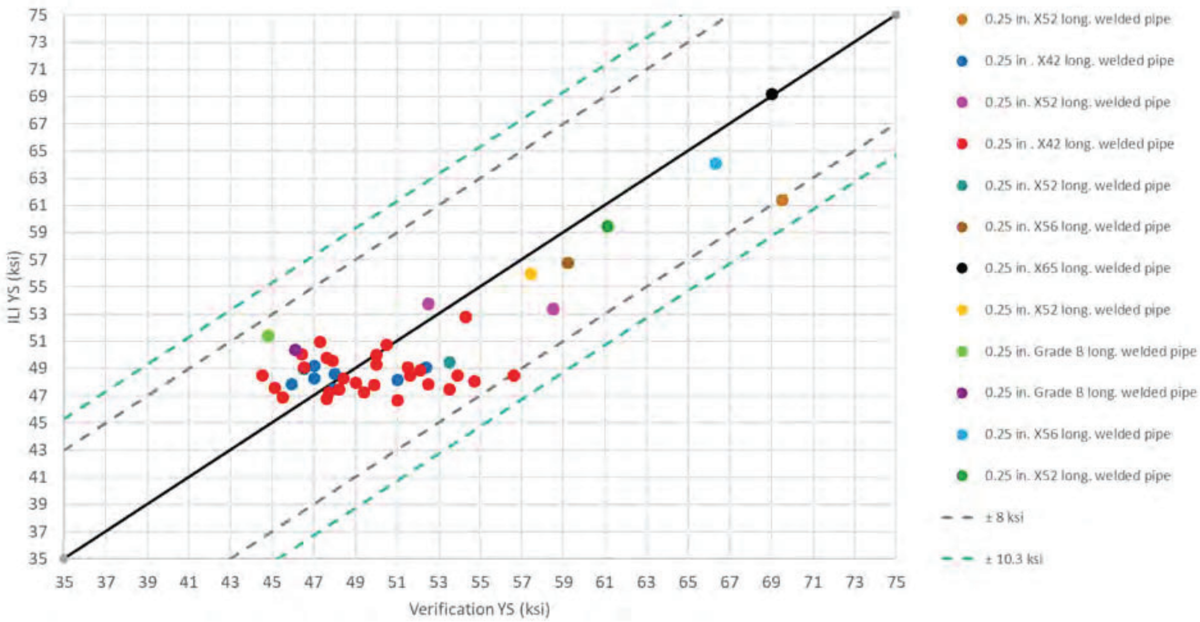

Figure 4. Example API 1163 Level 2 ILI System Validation Unity Plot

Once the ILI data was validated, the lower bound 95% confidence YS was calculated by subtracting 10.3 ksi (the ILI tolerance at 95% confidence) from the lowest strength pipe in the population. The grade was then assigned by comparing the lower bound YS to the expected non-TVC grade or next lowest API 5L grade, depending on the data sources available.

2.3 Assigning Other Material Properties and Attributes

Although strength is known to vary as a normal distribution within a single pipe population, nominal outside diameter, nominal wall thickness and seam type are constant within a population. Since the population assessment has shown that all pipes within a population have shared material properties, the nominal outside diameter, nominal wall thickness and seam type only need one verification in any population. Nevertheless, these properties are verified during all testing, therefore any test performed for strength will include testing of the other variables.

3. Applying Alternative Sampling to the 8" Dow Pipeline Segment

In 2022, Dow completed a RoMat PGS campaign on their 8" pipeline segment. The project resulted in eleven different pipe and bend populations, as shown in Figure 5 below.

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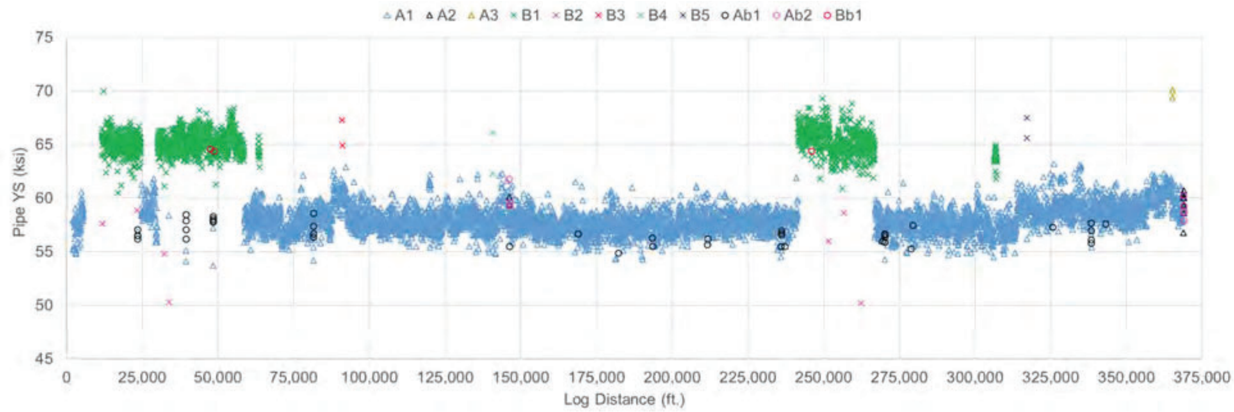

Figure 5. Strength vs. Log Distance of Dow's 8" Pipeline Segment (each point is a joint of pipe)

Ten of these populations needed further material property verification, as TVC documentation was not available. Most of these populations were less than one cumulative mile in length and were in accessible areas that allowed verification efforts to occur. In two of the populations, the alternative sampling methods described above were leveraged to reduce the amount of testing required.

3.1 Method A example

The Method A alternative sampling approach was leveraged for a 55.2-mile population (A1) that was originally installed in 1977. Dow provided two original design records that indicated pipe specifications including nominal diameter, nominal wall thickness, grade, seam type and manufacturer. However, these records were not traceable to specific locations along the pipeline; therefore, the material properties were not considered TVC. RoMat PGS reported values that corroborated the expected values in the non-TVC documentation, which are shown in Table 1 below.

Table 1. Material Properties for Population A1 in 08MOSKAP

Source	Outside Diameter (in.)	WT (in.)	Grade	Seam Type
Documentation	8	0.312	X52	ERW
RoMat PGS	8	0.312	X52	Longitudinally Welded

When considering the overall length of this population and since RoMat PGS corroborates the documented material properties, this population was an ideal candidate for alternative sampling. The required number of tests based on the default one per mile approach would have been 56. Using the approved alternative sampling method, this population was reduced to fourteen (14) tests (75% reduction of testing locations).

These fourteen tests will be performed either destructively or non-destructively, and the test results will be assessed using equation (1). If the YS value of the resulting lower bound 95% limit is higher than 52 ksi (SMYS for X52), testing will be complete, and the material properties considered TVC for population A1. If the resultant lower bound YS limit is lower than 52 ksi, the number of tests would increase to 50% of the cumulative length (28 tests) and the results would be re-evaluated after the additional tests are complete.

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Cost savings for this sampling approach are significant (between $420,000 and $2.5 million), especially considering that testing could be performed on excavations driven by other reasons, such as other integrity assessments or for operational reasons.

3.2 Method B example

The Method B alternative sampling approach was used for population A3, which has a cumulative length of 35.9 feet and is located under a river crossing. Dow provided two design records that relate to the original construction of the line segment. Available GIS data indicates this population was installed in 2009 (satellite imagery corroborates this through visible ground disturbance). The date discrepancy between original construction (1977) and 2009 make the documents non-TVC. The material properties specified in non-TVC documents are corroborated by RoMat PGS and shown in Table 2 below.

Table 2. Material Properties for Population A3 in 08MOSKAP

Source	Outside Diameter (in.)	WT (in.)	Grade	Seam Type
Documentation	8	0.312	X52	ERW
RoMat PGS	8	0.312	X52	Longitudinally Welded

Due to the overall length of this population and its' location under a river crossing, an opportunistic test to verify the material properties may never become available. Since this population has the same ILI material properties as population A1, the opportunity presents itself to leverage alternative sampling using ILI alone.

Using this alternative approach, no physical testing will be performed in population A3. The testing completed on populations A1 and A2 will be used to perform an API 1163 Level 2 validation to confirm the ILI performance specification has been met. Once validation is complete, the ILI 95% confidence tolerance (10.3 ksi) will be subtracted from the lowest ILI strength value in A3 population. The lowest measured ILI YS for the pipes in population A3 is 69.4 ksi. Subtracting 10.3 ksi from this value gives a lower bound YS limit of 59.1 ksi, which is higher than X52. Assigning a grade of X52 would be appropriate for this population as both documentation and validated ILI indicate the grade is at least X52. The other material property values from ILI for wall thickness, diameter and seam type will be assigned following completion of ILI validation in the other populations.

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4. Conclusion

ROSEN has developed two alternative sampling approaches that have both received no-objections from PHMSA. These approaches provide the required level of confidence that data from alternative sampling is valid.

Utilizing ILI measurements is a reliable way to gather material property values. Strength measurements from ILI are particularly useful for delineating populations, identifying lower strength outliers, and most importantly, enabling the use of alternative sampling approaches. Without the strength measurements from ILI, the alternative sampling methods described in this paper would not be possible. The ILI strength measurements indicate that each pipe is assigned to the correct population. Correctly assigned populations provide justification that test results in a population represent the proper grade of that population. As a result, fewer tests can be performed to achieve at least the same level of confidence that one test per mile would achieve, which ultimately saves time, effort, and money for the operator.

References

[1] Amend, B. "Using Hardness to Estimate Pipe Yield Strength." American Society of Mechanical Engineers, CRTD Vol. 91, 2012.

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