BEFORE THE NEW YORK STATE
PUBLIC SERVICE COMMISSION

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Petition Seeking Approval for :
Alternative Gas Service Line :
Inspection Intervals. : Case 15-G-0244
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CON EDISON PETITION SEEKING APPROVAL FOR ALTERNATIVE GAS SERVICE LINE INSPECTION INTERVALS

October 31, 2024

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I. Introduction

In 2019, the Commission authorized Consolidated Edison Company of New York, Inc. ("Con Edison" or the "Company") to extend gas service line survey and inspection intervals to five years, subject to the successful completion of a pilot program.[1] In doing so, the Commission suggested it would consider approving longer intervals (*e.g.*, ten years, which the Company originally sought) after the pilot program ended.[2]

The Commission should now extend the survey and inspection intervals to ten years. The pilot program ended in January 2023, and since the Order extending the survey and inspection intervals, Con Edison has enhanced several of its risk mitigation measures and gathered additional data justifying longer intervals. First, both a report published by the Gas Technology Institute ("GTI") on indoor meter sets[3] and the results of Con Edison's baseline/follow-up

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[1] Case 15-G-0244, *Proceeding on Motion of the Commission to Develop Implementation Protocols for Complying with Inspection Requirements Pertaining to Gas Service Lines Inside Buildings*, Order Granting Consolidated Edison Company Request for Authorization to Survey and Inspect Inside Gas Services In Alternative Intervals on a Pilot Basis With Conditions (issued October 21, 2019). ("Order")

[2] Order, p. 25.

[3] Indoor Atmospheric Corrosion and Leak Survey Risk Based Intervals, Final Report, GTI Project 25858, August 2017. This report includes several supporting Appendices and Addendum sections including a supplemental gap analysis evaluation to ensure conformance of this study with API RP-580 Risk Based Inspections ("RBI") and other historical studies that support this request. (Appendix A)

inspections demonstrate that inside gas service lines pose a low risk of corrosion or leaks. Second, the Company's enhanced risk mitigation measures, including the installation of Advanced Metering Infrastructure ("AMI") Enabled Natural Gas Detectors ("NGDs") with ten-year battery/sensor lives, provide an equal or greater overall level of safety than line inspections with shorter intervals. Lastly, extending the intervals will result in cost savings for customers.

II. Background

In October 2019, the Commission extended gas service line survey and inspection intervals, subject to certain conditions, to five years for business districts, non-business districts,[4] room sets, and new construction.[5] The Order established a three-year pilot program, beginning on January 1, 2020, and required Con Edison to report on the results. Pending Commission action on the report, the Order authorized the Company to continue performing inspections at the extended intervals.

The Order also suggested that the results of the pilot program might support longer intervals for room sets and new construction (ten years):

> The Pilot further will test whether elongated inspection intervals, with the conditions included in this Order, including, but not limited to the installation of AMI-enabled methane detectors at each inspected meter meets or exceeds existing safety standards. The GTI

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[4] In a separate but related development, the Pipeline and Hazardous Materials Safety Administration ("PHMSA") extended the survey and inspection intervals for non-business district locations to five years (from three years). Pursuant to the Commission's March 18, 2022, order in Case 19-G-0736, this modification to federal regulations was adopted in New York State, which made the Company's request to extend survey and inspection intervals to five years for non-business districts moot.

[5] The Company had proposed: (1) a five-year survey/inspection interval for both business districts and non-business districts (not to exceed 63 months); (2) a ten-year survey/inspection interval for room set locations (not to exceed 123 months); and (3) for newly constructed services, an initial survey/inspection after installation of 10 years (not to exceed 123 months) with all subsequent surveys/inspections to be completed at five-year intervals (not to exceed 63 months). *See* Case 15-G-0244, Proceeding on Motion of the Commission to Develop Implementation Protocols for Complying with Inspection Requirements Pertaining to Gas Service Lines Inside Buildings, Consolidated Edison Company Of New York, Inc. Request For Authorization Of Alternate Survey And Inspection Intervals (filed May 15, 2019). ("2019 Petition").

> study, Con Edison's system-wide baseline inspections, and the Company's opportunistic inspections, support that likelihood and, depending on future findings in the Pilot, could support the elongated, 10-year, intervals Con Edison seeks. However, further data collection is needed before longer intervals will be adopted.[6]

In January 2023, the Company submitted its Final Pilot Report.[7] As described below, the Final Pilot Report justifies extending the intervals.

III. Discussion

The Commission was correct in its prediction that the results of the pilot program, along with the GTI Report and the results of the Company's baseline and follow-up service line inspections, would support further extending the test and inspection intervals. As described below, this information and the Company's enhanced risk mitigation measures, including the installation of AMI-Enabled NGD with ten-year battery/sensor lives, justify granting this petition.

A. GTI Report Results

Beginning in 2016, New York State gas utilities worked with the Northeast Gas Association to evaluate a risk-based inspection interval under GTI's guidance. The resulting GTI study conformed to the American Petroleum Institute Recommended Practice 580 Risk Based Inspection ("API 580"). API 580 is an industry standard for developing risk based alternative inspection intervals.

The GTI Report describes field data from random indoor leak surveys and atmospheric corrosion inspections and includes an addendum describing opportunistic inspections completed

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[6] Order, p. 25.

[7] Case 15-G-0244, *Proceeding on Motion of the Commission to Develop Implementation Protocols for Complying with Inspection Requirements Pertaining to Gas Service Lines Inside Buildings*, Final Pilot Report (filed January 30, 2023).

over the same period. The results of the random sampling and probabilistic analysis, coupled with appropriate historic data, consequence analysis, and design considerations, provide a valid statistical analysis for developing recommendations for risk-based inspection intervals for indoor service piping.[8]

The study considered operating variables that included rural/urban vs. coastal/industrial areas; year of installation; conditioned vs. non-conditioned spaces;[9] meters above and below grade; commercial, multi-unit, and single unit sites; point-of-entry piping, meter rooms, and room set meters; and vented vs. non-vented spaces. The random sample enables the study to be used to apply the sample results to the broader population. The study relied on a standard approach for atmospheric corrosion inspections and indoor piping leak surveys. This approach established a consistent and repeatable process for grading indoor asset corrosion severity and assessing any indoor piping leak indications. For example, operators received atmospheric corrosion visual comparators/guides and step-by-step checklists, along with a standardized spreadsheet to collect and submit their survey results. Leak surveys were conducted using a combustible gas indicator, with a threshold detection limit of 0.1% gas-in-air (typical instruments used to perform indoor piping leak investigations). The gas utilities completed a total of 15,505 random indoor corrosion and leak surveys, representing a statistically significant number of data points, which resulted in high confidence levels of 90% to 95% when applying the sample results to both the broader New York population or each individual operator’s indoor asset population.

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[8] The gas utilities conducted the programmatic sampling effort over approximately a one-year period beginning in 2016 to assess typical indoor environmental operating variables an operator may experience in day-to-day operations. This strategic approach allowed for inspection sampling of several operators’ jurisdictional service piping over the course of one complete cycle of seasons to determine the probability and severity (with confidence levels) of indoor, atmospheric corrosion and leak survey results as a function of system attributes and location. All the operators classified their sample sites as indoor, room sets, or building point of entry.

[9] Please see GTI Report (Appendix A), p. 19 for an explanation of conditioned and non-conditioned spaces.

The corrosion severity (four levels) and number of leak indications (based on a 0.1% gas threshold) were analyzed for the random survey set and summarized for New York State (all New York Operators combined), and by individual operator. The survey results were also reported in sub-groups such as: indoor meters and piping (with and without room sets), building point of entry penetration, and for room sets only.

The New York State results show that for corrosion severity, 81% of the sites inspected had none/minimal corrosion, 14% low corrosion, 4% medium corrosion, and less than 1% high corrosion levels. The study showed that 99% of the sites exhibited no leak indications, while less than 1% had an indication of a leak with a median leak indication concentration level of 0.15% gas, which is less than the combustible level.

The high-level summary of NY Corrosion and Leak Survey Results is shown in Table 1.

Table 1 – GTI Report Results

Random Inspection Corrosion and Leak Survey Roll up	NY Operators Combined	
	Numbers	Percent
None/Minimal Corrosion	10,204	80.67
Low Corrosion	1,829	14.46
Medium Corrosion	556	4.40
High Corrosion	60	0.47
Sub-Totals	12,649	100.00
No Leak Indication	12,478	99.05
Leak Indication (.01% or greater of gas on CGI)	120	0.95
Sub-Totals	12,598	100.00

These results demonstrate that on a statewide basis there is a low probability of significant corrosion on inside piping and an even lower probability of leaks.

B. Company Baseline Inspection Results

As part of the pilot program, the Company committed to re-inspecting a statistically valid and randomly selected sample of locations from those that had received a baseline survey or inspection prior to December 31, 2019. The Company had initially targeted approximately 9,000 locations with AMI-enabled NGDs for re-inspection, but later expanded the number of locations to include opportunistic re-inspections. This expansion was due in part to difficulties the Company experienced in gaining access to locations because of the COVID-19 pandemic. Ultimately, the Company performed over 89,000 re-inspections.[10]

As set forth in Table 2, the results of the re-inspections are consistent with those of the statewide GTI Report.

Table 2 – Pilot Program Results

Inspection Results	Number of Inspections	Percent of Findings per Inspection
None/Minimal Corrosion	61,776	69.18
Low Corrosion	25,652	28.73
Medium Corrosion	674	0.75
High Corrosion	1,196	1.34
Sub-Totals	89,298	100.00
No Leak Indication	89,207	99.90
Leak Indication (.01% or greater of gas on CGI)	91	0.10
Sub-Totals	89,298	100.00

Overall, the re-inspection results demonstrate that risk is even lower than indicated by the GTI Report. Although the Pilot Program results indicate a higher percentage of Low Corrosion conditions compared to the statewide GTI Report, the combined findings for Medium and High Corrosion conditions were lower under the Pilot Program findings than they were under the GTI

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[10] These 89,298 re-inspections were performed randomly and have a high level (99%) of statistical validity.

Report. The Medium and High Corrosion findings under the Pilot Program yields a 2.09% rate, compared to the 4.8% rate under the statewide GTI Report. Moreover, of the re-inspection locations with Medium and High Corrosion findings, only 91 had a leak associated with the corrosion, for a rate of 0.103%. This is much lower than the leak rate found in the statewide GTI Study (0.95%).

As noted above, the COVID-19 pandemic affected the Company's ability to gain access to customer locations to perform re-inspections. The pandemic also had an impact on the Company's planned implementation for AMI-enabled NGDs on Business District services. Prior to the pandemic, the Company had planned for full implementation of NGDs on Business District services by December 31, 2022, and full implementation on all gas services by December 31, 2025. As of October 1, 2024, the Company has installed NGDs in more than 69% of premises with a gas service and is targeting completing initial deployment by December 31, 2025.

The Company has recently completed its inside gas service line baseline inspection program.[11] Since the inception of the program, the Company has inspected nearly 100% of all gas meters at least once.[12] Between 2017-2022, there were a total of nearly 1,700 corrosion findings on a unique meter. This represents corrosion findings of less than 0.2% on the inspected gas meters, or little or no corrosion findings on 99.8% of gas meters inspected. Of the 1,700 corrosion findings on gas meters, only 131 findings were on meters that were located within a customer's apartment. Gas meters located within a customer's apartment represent nearly 20% of the meters in our service territory. Atmospheric corrosion, when discovered at a premise, is more likely to be identified at the point of entry or on jurisdictional piping located in a customer's

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[11] Case 15-G-0244, Final Con Edison Baseline Gas Service Line Inspection Report (filed August 22, 2024).

[12] Service has been terminated to premises where access was not provided to perform the required inspections.

basement. The likelihood for corrosion to be discovered on the components located in a customer's apartment is extremely low. This is illustrated by the 2023 corrosion rates, which show that only 0.21% of apartment meters were found to have Level 3 or Level 4 corrosion in 2023.

Table 3 – 2023 Corrosion Rates

Con Edison SLI Program 2023 - Corrosion Rates				
Corrosion Condition	**Company Piping – POE**	**Customer Piping – Extension Service**	**Non-Apartment Meter**	**Apartment Meter**
1 - None to Minimal	67.34%	66.93%	81.23%	83.50%
2 - Low	30.52%	32.29%	18.41%	16.29%
3 - Medium	0.57%	0.43%	0.26%	0.15%
4 - High	1.57%	0.34%	0.11%	0.06%
Combined 3 & 4	2.14%	0.77%	0.37%	0.21%
Combined 1 & 2	97.86%	99.22%	99.63%	99.79%

As demonstrated in Table 3, above, inspection data shows that point of entry is the most likely location on a service to discover significant corrosion (2.14% percent of POEs found to have Level 3 and 4 corrosion in comparison to 0.21% percent of apartment meters in 2023). These results provide additional data refining and further corroborating the findings under the GTI Report and the Pilot that there is a low probability of Medium or High Corrosion on inside piping, particularly piping inside apartments.

C. Additional Risk Mitigation Efforts

In addition to gas service line surveys/inspections, Con Edison maintains safety by identifying and addressing risks through its Distribution Integrity Management Plan ("DIMP").[13] Under the DIMP framework, the Company employs a strategy focused on prevention, detection,

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[13] The Company notes that Department of Public Service Staff periodically audits the Company's DIMP. Results of the last audit DPS Staff performed were issued in October 2022.

and response. This strategy is illustrated by the examples of risk mitigation measures set forth and described below. Taken together, these measures should give the Commission confidence that it can extended the service line inspection intervals while maintaining safety.

1. AMI-Enabled Natural Gas Detectors

After running a successful pilot program, in 2020 Con Edison began installing AMI-enabled natural gas detectors throughout its service territory. These detectors alarm locally and notify the Company that there is a gas emergency requiring immediate dispatch. Initially, the devices had a six-year battery/sensor life, but now have a life of ten years. While inspections are useful, having a real time indication of a low-level methane leakage and an alarm (either locally from a residential methane detector or through our AMI-enabled NGDs) that triggers an emergency response provides an even greater level of safety. As of October 1, 2024, the Company has installed natural gas detectors in more than 69% of premises with a gas service. The Company expects to complete service-territory deployment by December 31, 2025.

2. Pipeline Safety Management System

The American Petroleum Institute's Recommended Practice (API RP 1173) lays out the elements of an effective and holistic gas Pipeline Safety Management System ("PSMS") for pipeline operators. Through Con Edison's PSMS, the Company follows a Plan-Do-Check-Act cycle for daily activities, which promotes continuous improvement and feedback loops to the Company's existing practices, procedures, and management systems. The application of this standard can be seen throughout our DIMP and Transmission Integrity Management Program ("TIMP"). Our Integrity Management Programs support efforts to identify emerging areas of risk and allow the Company to take proactive steps to address them.

PSMS assesses the Company and its programs through the lens of ten safety-related elements. Con Edison set out to comply with the ten elements of PSMS in 2016. In 2019, the Company received a score of “conformance” to the API Recommended Practice 1173 through an external review. In 2023, the Company’s PSMS was reviewed again by an external party and received a score of 4.45 out of 5.0, certifying “effectiveness.” In line with effective Integrity Management Programs and solid emergency response protocols, application of the PSMS standards further enhances overall public safety and risk mitigation culture. The Company plans to continue conducting regular independent audits of its PSMS efforts to ensure continuous improvement of risk mitigation and safety protocols.

3. Leak Response and Partnership with Fire Departments

Con Edison responds to more than 95% of odor calls within thirty minutes and partners closely with local fire departments on leak response and immediate make safe actions (*e.g.*, isolation, evacuation, etc.). Through training, drills, combined field response and lessons learned reviews, awareness of gas safety response and make safe protocols is very high among our local fire departments, increasing our ability to quickly and safely respond to gas odor calls.

4. Leak Surveys

In addition to a mandated annual leak survey of all the Company’s mains, Con Edison performs low-speed mobile leak surveys every month of its entire distribution main system. This protocol increases the Company’s ability to find and repair leaks before receiving an odor call. Also, in 2023 Con Edison began an annual high emission survey to detect leaks that emit >10 SCFH of gas. Each year, Con Edison will survey one third of the gas system for high emitting leaks and repair them on an accelerated schedule.

5. Leak Repairs, Main and Service Replacement

Under the Company's current Gas Rate Plan, the Company is incentivized to repair 85% of all leak (regardless of whether repair is required by regulation) within 50 days.[14] Once a leak is identified on the Con Edison system, repairs are timely made. Fixing all leaks in a timely manner is consistent with the Company's philosophy of keeping its neighbors safe and reducing greenhouse gas emissions. All leak and leak repair data, as well as many other factors, are used to inform our Gas Infrastructure Replacement & Reduction Program ("GIRRP") This is a preventative measure that increases the level of safety on a system wide basis.

6. Expansion of Use of Detection Technology

The AMI-enabled NGDs are installed in the basement of a home or building, close to the point of entry where the gas service enters the building. As discussed above, this is the most likely location for corrosion to occur. This device will not detect a leak that could occur inside a customer's apartment or living space. New York City Local Law 157 (2016) was amended in 2024 and requires the installation of natural gas detecting devices in residential buildings near the gas appliance (such as the stove or dryer) by May 1, 2025. This provides an added level of safety for our customers who can call Con Edison's emergency response or 911 (FDNY) in the event the appliance-adjacent device alarms.

D. Cost Savings

Finally, approving the extended survey and inspection intervals as proposed by the Company will result in cost savings for customers. The Company currently estimates that operations and maintenance ("O&M") expenses could be reduced by $16 million annually if this

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[14] Case 22-G-0065, *Proceeding on Motion of the Commission as to the Rates, Charges, Rules and Regulations of Consolidated Edison Company of New York, Inc. for Gas Service*, Order Adopting Terms of Joint Proposal and Establishing Electric and Gas Rate Plans with Additional Requirements, (issued July 20, 2023), Appendix 19.

petition is approved. The Company would be open to addressing these cost savings as a negative program adjustment if a base rate proceeding is pending when the Commission approves this petition.

V. Conclusion

Because of the low risk posed by inside gas service lines, the risk mitigation measures the Company has implemented and the potential cost savings for customers, Con Edison respectfully requests that the Commission approve the Company's proposal to extend current survey and inspection intervals for inside gas service lines from five years to ten years.

Dated: New York, New York
October 31, 2024

Respectfully submitted,

CONSOLIDATED EDISON
COMPANY OF NEW YORK, INC.

By its Attorney

/s/ Enver Acevedo
Enver Acevedo
Associate Counsel

4 Irving Place
Room 18-835
New York, NY 10003
Office: (212) 460-3762
Mobile: (917) 439-9836
acevedoe@coned.com

APPENDIX A

the Energy to Lead

GTI PROJECT (21858)

Indoor Atmospheric Corrosion and Leak Survey Risk-Based Intervals

Final Report

Revision 3 – August 2, 2018

(Original Report Date: August 25, 2017)

Submitted To

Northeast Gas Association (NGA)

GTI Technical Contact
Mr. Daniel Ersoy
R&D Executive Director
Gas Technology Institute
847.343.9755
daniel.ersoy@gastechnology.org

Authors
Daniel Ersoy, M.Sc., CIP, APMP
Khalid Farrag, PhD, P.E., PMP

Gas Technology Institute
1700 S. Mount Prospect Rd
Des Plaines, Illinois60018
www.gastechnology.org

Signature Page

		Date
AUTHOR Daniel A. Ersoy	Daniel Ersoy//S//	August 2, 2018
	Title: R&D Executive Director, GTI	
CO-AUTHOR Khalid Farrag	Khalid Farrag//S//	August 2, 2018
	Title: Sr. Institute Engineer, GTI	
REVIEWED BY Daniel Dessanti	Daniel Dessanti//S//	August 2, 2018
	Title: Project Manager, NGA	

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The results within this report relate only to the items analyzed.

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Executive Summary

This report describes the development and execution of a sampling plan and methodology used by New York (and one New Jersey) state operators to gather field data to evaluate the appropriate frequency for mandated inspections of indoor jurisdictional piping and appurtenances. More specifically, these inspections included indoor jurisdictional piping leak surveys and atmospheric corrosion inspections. This final report focuses on the random survey results and analysis. An attached addendum to this report provides an additional summary of a separate set of opportunistic surveys completed over the same time frame. The results of the random sampling and probabilistic analysis, coupled with appropriate historic data, consequence analysis, and design considerations can be used to develop recommendations for risk-based inspection intervals for indoor piping systems as part of an operators Distribution Integrity Management Program (DIMP).

The programmatic sampling effort was conducted over approximately a one-year period in 2016 to address typical indoor environmental operating variables an operator may experience in day-to-day operations. This strategic approach allowed for an adequate set of random inspection sampling of the New York and New Jersey operator's indoor atmospheric systems throughout one complete cycle of seasons. A total of nine New York and one New Jersey operator participated in the random corrosion and leak surveys. All the operators, except for the New Jersey operator classified their sample sites as indoor, room sets, or building point-of-entry (POE). Since the full protocol was not followed by the New Jersey company, data and analysis is located separately in the Appendix B of this report. The body of the report is applicable to the state of New York.

A properly designed random sampling plan coupled with statistical analysis was carried out to determine the probability and severity (with confidence levels) of indoor, atmospheric corrosion and leak survey results as a function of system attributes and location. The sampling plan was designed to ensure an unbiased randomly selected set of locations representative of NY State operating areas. Operating variables considered in plan design and sample selection included rural/urban vs. coastal/industrial areas; year of installation; conditioned vs. non-conditioned spaces; meters above and below grade; commercial, multi-unit, and single unit sites; point-of-entry piping, meter rooms, and room sets; and vented vs. non-vented spaces. The random sample was vital to ensure that conditional probability analysis could be conducted to infer the sample results to the broader population, thereby allowing for the calculation of confidence limits on predictions that consider uncertainty.

A comprehensive, standardized protocol for conducting both atmospheric corrosion inspections and indoor piping leak surveys was developed and implemented. Atmospheric corrosion visual comparators/guides and step-by-step checklists were provided to the operators, along with a standardized spreadsheet to collect and submit their survey results. The protocol ensured a standard and repeatable approach to grading indoor asset

corrosion severity and assessing any indoor piping leak indications. Leak surveys were conducted utilizing a combustible gas indicator, with a threshold detection limit of 0.1% gas-in-air (typical instruments used to perform indoor piping leak investigations).

A total of 15,505 random indoor corrosion and leak surveys were completed, 12,864 of which were located in New York State. This is a very large number of NY data points which allowed for the selection of high confidence levels of 90% to 95% when inferring the sample results to the broader NY or even operator-by-operator indoor asset population.

The results of the random surveys were analyzed by the variables recorded for each inspection, and showed there were approximately 61% of the sites conditioned and 39% unconditioned; 83% were in urban or rural geographic locations and 17% in coastal or industrial locations; about 54% of the sites were at the building point-of-entry (POE) penetration and for the other 46% of survey sites the meter locations were near the POE in about 48% of the cases; 28% were pre-1965, 34% 1965-1990, and 38% post 1990 installations, 44% were single family dwellings, 48% multi-unit, and 8% commercial or industrial sites.

Descriptive statistics were calculated for environmental variables measured at each inspection site (temperature and relative humidity), as well as the individual site system pressures. The temperature and relative humidity levels measured over the sampling year of 2016 were normally distributed and representative of past indoor corrosion studies that covered the NY area.

The corrosion severity (four levels) and number of leak indications (based on a 0.1% Gas threshold) were analyzed for the random survey set and summaries by NY State (all NY Operators combined) and by individual operator. The survey results were also reported out in sub-groups such as: indoor meters and piping (with and without room sets), building point-of-entry (POE) penetration, and for room sets alone.

The high-level summary shows that for corrosion severity there were 80.7% with none/minimal corrosion, 14.5% low corrosion, 4.3% medium corrosion, and less than 1% with high corrosion levels. The proportion of the samples related to leak indications showed that 99% of the sites exhibited no leak indications while less than 1% had an indication of a leak with a median leak indication concentration level of 0.15% Gas.

The high-level summary of NY Corrosion and Leak Survey Results are shown in the table below.

Corrosion Inspection Summary for Combined NY Operators

Random Inspection Corrosion and Leak Survey Roll Up	NY Operators Combined	
Corrosion Summary	**Numbers**	**Percent**
None/Minimal Corrosion	10,204	80.7
Low Corrosion	1840	14.5
Med Corrosion	545	4.3
High Corrosion	60	0.5
Sub-Totals	12,649	100.00
Leak Indication Summary	**Numbers**	**Percent**
No Indication	12,478	99.05
Leak Indication (≥ 0.1% Gas on CGI)	120	0.95
Sub-Totals	12,598	100.00

The analysis of indoor meters and piping vs. the building POE penetration locations showed that for indoor meter and associated piping (non-POE) sites 12 of 5,752 (or 0.21%) had high corrosion severity and 16 of 5,757 (or 0.28%) exhibited leak indications at 0.1% Gas or higher. Whereas, for building POE penetration locations 48 of 6,897 (or 0.70%) had high corrosion severity and 104 of 6,841 (or 1.52%) leak indications at 0.1% Gas or higher. On a relative basis, 48 sites of the 60 high corrosion sites (or 80%) and 104 out of the 120 leak indications sites (or 87%) were in the building POE penetration locations. This illustrates greater propensity for potential corrosion and leak indications at building POE penetration sites. Analyses were provided for a subset of NYC data that can be found in sections 4.4 and 6.4.

A variable sensitivity analysis was conducted to determine what variables correlated to observed corrosion severity and leak indications. The categorical levels for corrosion and leak indication were assigned an ordinal number that was used to calculate average values for corrosion and leak indexes. A comparison of means (averages) was conducted for each variable category to determine if there was a statistical difference between it and the remaining categories for the variable. This was supplemented with an analysis of variation (ANOVA) regression analysis to confirm the significant variables (inclusive of all categories) as related to the corrosion and leak indications. Based on these two sensitivity checks, the variable categories that correlated to higher corrosion or increased leak indications were noted. Those categories that did not show statistical difference between their mean index levels and all the remaining categories for the variable were coded as being neutral. The five “sensitive” variable categories for Corrosion (and only four of the five for Leak Indications) that correlated to increased average corrosion and leak index values:

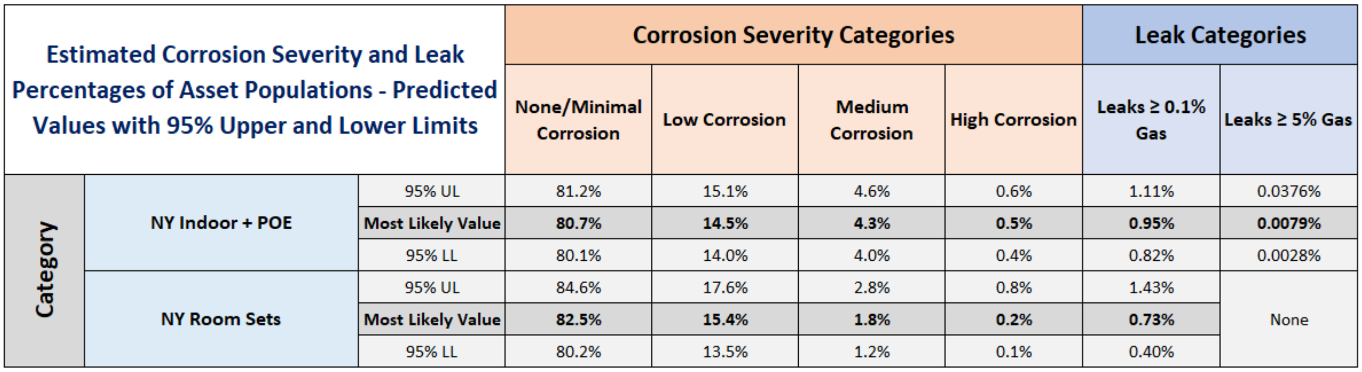
- Non-Conditioned Spaces
- Urban/Rural Geographic Locations
- Below Grade Asset Location
- Commercial/Multi-Unit Dwelling Type (for Corrosion Severity only)
- Meter Location within Building (i.e., indoor meters and piping near the POE location)

In addition to this sensitivity analysis on the variables, the comparison of results, i.e. comparing corrosion severity levels to leak indications, showed that leak indication locations had on average a 21% higher corrosion severity index with a significant separation of the mean confidence intervals.

Conditional probability analysis was used to calculate the probable corrosion severity and leak indication levels for each major category of assets in the entire NY (and by operator) indoor, aboveground asset *population* from where the random *sample* was drawn. These predictions include the most likely proportions of corrosion severity and leak indication rates along with lower and upper confidence limits that reflect the uncertainty in the predictions.

The highest level roll up is shown in the table below.

Population Predictions for Corrosion Severity and Leak Levels - NY Roll Up



Estimated Corrosion Severity and Leak Percentages of Asset Populations - Predicted Values with 95% Upper and Lower Limits			Corrosion Severity Categories				Leak Categories	
			None/Minimal Corrosion	Low Corrosion	Medium Corrosion	High Corrosion	Leaks ≥ 0.1% Gas	Leaks ≥ 5% Gas
Category	NY Indoor + POE	95% UL	81.2%	15.1%	4.6%	0.6%	1.11%	0.0376%
		Most Likely Value	**80.7%**	**14.5%**	**4.3%**	**0.5%**	**0.95%**	**0.0079%**
		95% LL	80.1%	14.0%	4.0%	0.4%	0.82%	0.0028%
	NY Room Sets	95% UL	84.6%	17.6%	2.8%	0.8%	1.43%	None
		Most Likely Value	**82.5%**	**15.4%**	**1.8%**	**0.2%**	**0.73%**	
		95% LL	80.2%	13.5%	1.2%	0.1%	0.40%	

For example, for all indoor and building POE penetration assets (combined) we would expect there to be 0.5% of the population in the high corrosion severity with no more than 0.6% with a 95% confidence.

For leak indications there are two columns, one for Leaks ≥ 0.1% Gas (50x safety margin to methane LEL) and one for Leak indications ≥ 5% Gas (methane LEL). One can see that there is a less than 1 in 10,000 expected occurrence of leaks ≥ 5% Gas. We did not include this analysis for room sets since no leak indications in this range were observed in the sample set.

An additional probabilistic analysis was performed on a statistically significant number of leak indications, above and below the 0.1% Gas threshold, which were measured with both an ordinary hand-held CGI (with sample probe) and belt clip CGI detector (without sample probe). The true and false negative and positive indications showed significant variations between the belt clip sampling technique and traditional CGI measurements techniques within a confidence level of 96%.

The results of the sensitivity analysis were relatively ranked and prepared into a table that matches installation attributes (aka variable categories) for indoor meter and piping to a relative severity weight. The relative weights for each installation attribute variable can be added for an overall "likelihood" of severe corrosion/leak indication weighting. This overall likelihood severity weight can be multiplied with an operator-assigned consequence relative weighting to provide a relative risk weighting.

A relative weighting scale was developed based on the random sampling analysis that assigns a number from 1 to 15 (lower to higher likelihood risk) for each of the random sample variables that exhibited correlation to corrosion severity and leak indications. The relative likelihood weighting (Lw) assignments are shown in the table below. Additional details and examples can be found in Section 5.4 of this report

Relative Likelihood Weighting for Random Sample Variables by Installation Attribute

Random Sample Variable	Installation Attributes	Relative Likelihood Weight (Lw)
Building POE Penetration vs. Interior Meter and Piping vs. Room Set	Building POE Penetration	15.0
	Interior Meter/Piping Near POE	10.0
	Unknown	10.0
	Interior Meter/Piping Meter Room	5.0
	Interior Meter/Piping Multiple Locations	5.0
	Room Set	1.0
Past Corrosion Levels High or Medium Severity	Yes	10.0
	Unknown	5.0
	No	1.0
Conditioning	Conditioned	1.0
	Unknown	5.0
	Non-Conditioned	10.0
Rural/Urban or Coastal/Industrial	Rural or Urban	5.0
	Coastal or Industrial	1.0
Meter Grade	Below Grade	10.0
	Unknown	5.0
	Above Grade	1.0

The variable/category relative weightings and the population upper confidence limit proportions can be used as part of a DIMP-based, risk-weighted indoor, aboveground corrosion and leak inspection program - both for establishing initial base-line analysis schedules and for assessing an appropriate frequency of re-inspection post completion of base-line assessments.

This final report contains an *addendum* report that describes the data analysis from an opportunistic sampling plan and methodology used by four New York state operators to gather field data in 2016 to evaluate the appropriate frequency for mandated inspections of indoor jurisdictional piping and appurtenances. A total of 84,460 opportunistic inspections were submitted by the four NY operators. Opportunistic inspections might include situations like odor investigations, poor pressure complaints or other situations where properly qualified technicians respond to a location and gain access.

The data from the site surveys were combined and a trend analysis was performed. The opportunistic study showed that at a high level, the opportunistic inspections provided a similar understanding of the overall corrosion levels as a proportion of the population, as wells as the overall leak indication rates and can provide a useful tool for trend analysis of an operator’s system for these attributes. One should still rely on the random sample study to determine what variables could lead to higher corrosion severity and/or leak percentages.

The statistically sound data with confidence limits from this final report can be coupled with consequence considerations and guide operators to make appropriate company-by-company asset based, reasonably prioritized, base-line inspections coupled with properly set inspection intervals to maximize public safety value.

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Corrosion and Leak Survey Results

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Sensitivity Analysis of Results by Variables

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Population Predictions from the Sample Results

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Conclusions

Section 7

Appendices & Attachements

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2 Background

New York State DPS notified New York state utilities of a change in code which will update the definition of "Service Line" under Part 255.3(a) (29) to mirror the Federal definition under Part 192. This essentially changes the existing service line definition which limits Operator's responsibility for jurisdictional piping at the first fitting inside the building wall relative to the Federal definition which includes jurisdictional responsibility to the outlet of the meter, regardless of who owns the piping within the building.

Recognizing the complexity of this transition and obvious challenges associated with the practicality of the transition, Operators formed a collaborative through the Northeast Gas Association (NGA) to explore reasonable alternatives to implementation. More specifically, Operators suggested that there may be an opportunity for adopting a practical approach to implementation under current Distribution Integrity Management (DIMP) provisions based on a rigorous and technical risk assessment. This approach includes establishing an appropriate base-line inspection assessment period along with the reassessment of inspection intervals for atmospheric corrosion and leak surveys of jurisdictional pipe inside buildings with the specific intent to properly determine the timeframe between inspections based on the outcome of the risk assessment.

Operations Technology Development (OTD), NFP, engaged the Gas Technology Institute to review historical and current data on indoor service piping, as well as provide sound engineering guidance on all aspects of indoor atmospheric corrosion. GTI completed a white paper on the topic: *GTI White Paper No. 21678 - Risk-Based Atmospheric Corrosion/Leak Survey Considerations*, Issued October 27, 2014 [see Attachment Section of this report]. The paper presents the fundamental principles of indoor and outdoor atmospheric corrosion. The paper also provided a detailed review of the published, peer-reviewed literature related to field data on indoor corrosion, and compares and contrasts this to outdoor corrosion for iron and steel piping materials. The paper included the analysis of thousands of recent inspections in NY and New England States completed on outdoor and indoor services by operators. The data was statistically analyzed to determine the trends and drivers behind the observed corrosion rates. A similar analysis was completed on exclusively indoor leak survey data from LDC operators. Finally, all the findings were summarized and related to risk-based considerations for setting appropriate inspection intervals for indoor service piping.

NGA and NY Operators submitted formal comments to the NY PSC relative to the proposed rulemaking which focused on the use of Distribution Integrity Management principles to set inspection intervals and referenced the GTI white paper as a technical reference. On March 25, 2015 the NY PSC issued its revision to 16 NYCRR Gas Safety Regulations which revised the service line definition to align with the federal definition except for the implementation requirements which were stayed pending further Commission action.

The intent of this project is to provide the NY Operators and the NY PSC with a detailed risk assessment on interior jurisdictional pipe such that sound decisions can be made relative to initial base-line inspection time frame coupled with establishing appropriate re-inspection intervals in accordance with DIMP requirements all focused on maximizing public safety value.

There is a need to develop a risk-based program for inspection of indoor meter sets and associated indoor service piping for atmospheric corrosion and leak surveys – leading to statistically sound and engineering based initial inspection and subsequent re-inspection intervals for the same. Such a program should build on the technical information and guidance in the GTI White Paper No. 21678, supplemented with a rigorous random sample and analysis of the same indoor meter sets and associated jurisdictional service piping.

This report describes the development and execution of such a random sampling plan and methodology used by New York (and one New Jersey) state operators to assess the indoor atmospheric corrosion and leak surveys for each of their systems and as combined set representative of the NY State operational area.

A properly designed random sample coupled with statistical analysis was carried out to determine the probability and severity (with confidence levels) of indoor, atmospheric corrosion and leak survey indications as a function of system attributes and location. The results of this random sampling and probabilistic analysis, coupled with appropriate historic data, consequence analysis, and design considerations can be used to develop recommendations for risk-based initial inspections and subsequent re-inspection intervals for indoor jurisdictional piping systems.

3 New York State-Wide, Random Sample Size and Distribution

3.1 Random/Programmatic Indoor Atmospheric Corrosion and Leak Survey Inspections

This section provides a summary of the number of random sample inspections and opportunistic atmospheric corrosion and leak surveys in 2016 under this project. The field inspections in Table 1 below is through December 31, 2016. These numbers are rolled up into the overall assigned and completed, and are not specific by sub-category. Nine New York operators were included and one New Jersey operator[1].

The sampling plan/design can be seen in *Appendix D - Summary and Basis of Random Sampling Experimental Design* section of this report.

Table 1. Program Inspection Sampling Summary

Operator	Random Submitted	Opportunistic Submitted
NGrid	8,387	74,601
PSEG (NJ)	2,641	-
ConEd	2,996	9,334
RGE	584	1
NFuel	177	123
NYSEG	511	-
Cent Hud	64	401
ORU	121	-
St. Lawrence	24	-
Totals	***15,505***	***84,460***

3.2 Random Surveys

15,505 random surveys have been submitted for analysis in 2016. This data was higher than the 8,460 initially assigned data size (183%).

3.3 Opportunistic Inspections

A total of 84,460 opportunistic surveys were submitted for analysis in 2016. The results of the subsequent analysis is reported in an addendum of this final report.

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[1] PSE&G (New Jersey) did not classify their sites as Indoor, Room Sets, or POE. The majority of the metadata was also not included. Since the full protocol was not followed the New Jersey (PSE&G) data and limited analysis is located separately, and in its entirety, in *Appendix B - New Jersey (PSE&G) Limited Data Set and Analysis* of this report. Based on the limited variable information the analysis is focused on responses vs. the ability to include the variable sensitivity.

3.4 Random Sample Program - Variable Categories

3.4.1 Single Variable Random Sample Program Breakdown

3.4.1.1 Variable Explanation

The variables are noted in more detail with their categories in *Appendix C - Random Sampling Program Corrosion and Leak Survey Procedure & Forms*. The Appendix C procedure includes each variable and response that the survey crews recorded during the sampling. This appendix section also contains a copy of the spreadsheet that the data was recorded into, however the standardized drop-down selections cannot be seen, but are noted in the procedure.

3.4.1.2 Variables vs. Responses

The *variables* are used in the later Sensitivity Analysis section of this report to determine if particular variables and/or their categories exhibit a correlation to either of the two *responses* recorded in the survey, namely “Corrosion Severity” and “Leak Indication at 0.1% Gas or above”.

3.4.1.3 Basis of Variable Selection and Sample Size

The basis of which variable to record during the surveys is explained in *Attachment 1 - White Paper Risk-Based Atmospheric Corrosion / Leak Survey Considerations*. The basis of the sample size/design is explained in *Appendix D - Summary and Basis of Random Sampling Experimental Design*. The reader is directed to these two documents for additional details.

3.4.1.4 Variable Breakdown of Sample Set

The random sample data set from the state of New York is characterized in Figure 1 to Figure 10 in this section of the report. These figures break down each variable of the random sample set into their respective categories. The count/number of observations is annotated on the vertical axis and the percent of the sample set is noted as data labels above each category bar for the variable. There is also a category “blank” for each of the variables. If operators did not record the variable on the survey sheet these values were tallied as “blank”.

For example, in Figure 1, the variable “space conditioning” has the categories “Conditioned” or “Non-Conditioned” and their percentages of the total random samples are 61.1% and 38.7% respectively, with the “blank” category at 0.2%.

In summary, the variable category analysis shows a sample set that includes typical and realistic proportions of conditioned vs. non-conditioned, vented vs. non-vented, dwelling type, meter location, geographic location, installation year, etc. In short, it is representative of the population and was selected as to not be biased. The next section of the report goes one step further by analyzing and plotting a two-factor variable comparison.

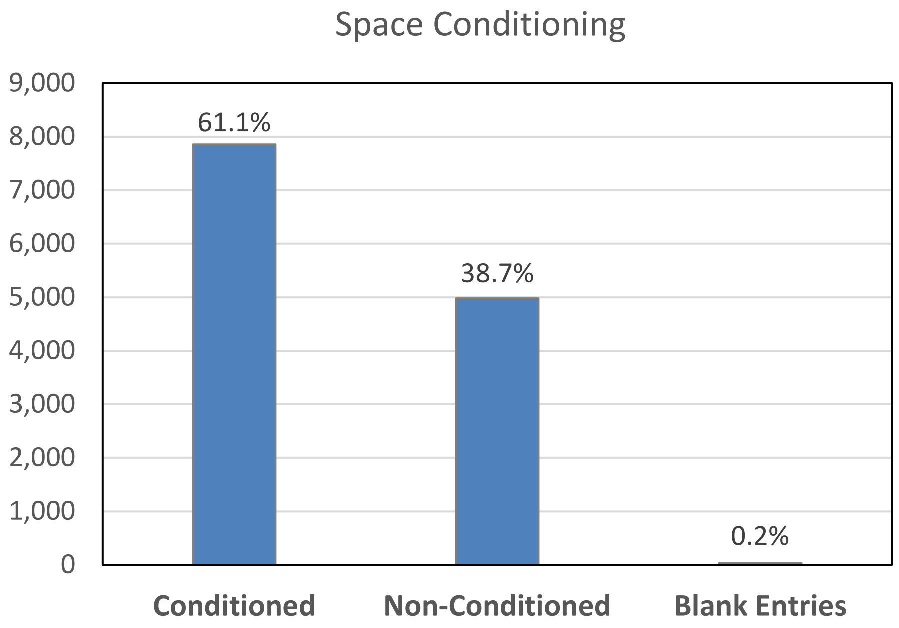


Figure 1. Percentage of Random Sample by Space Condition Categories

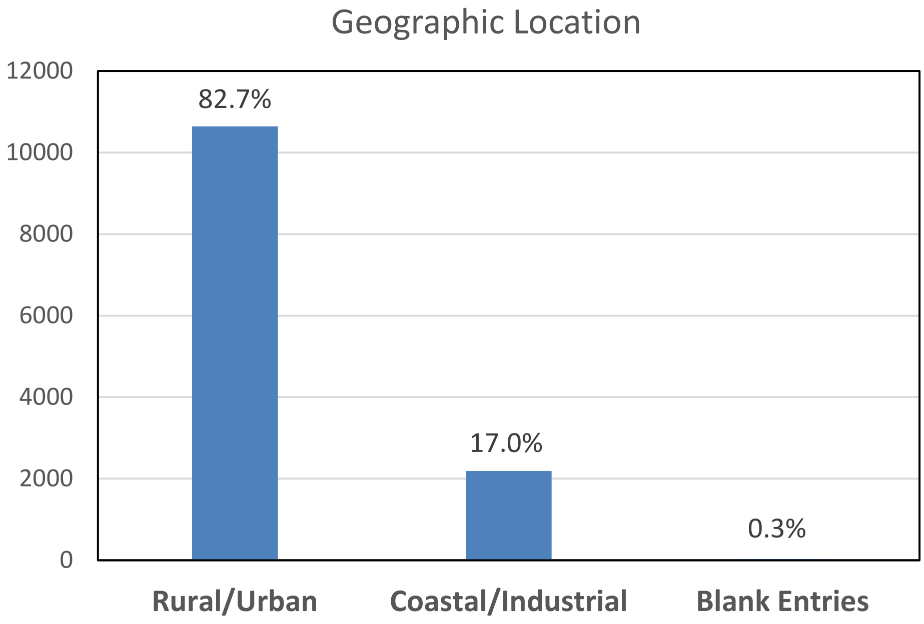
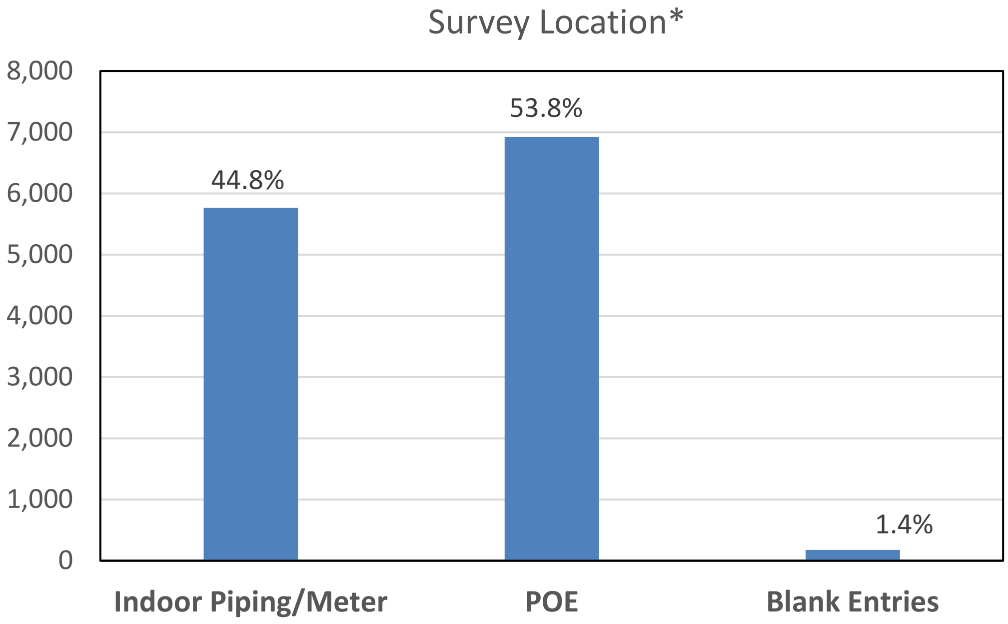


Figure 2. Percentage of Random Sample by Geographic Location Categories



**Note: POE means the survey was done on the piping specific to the location of building penetration.*

Figure 3. Percentage of Random Sample by Meter Location Categories

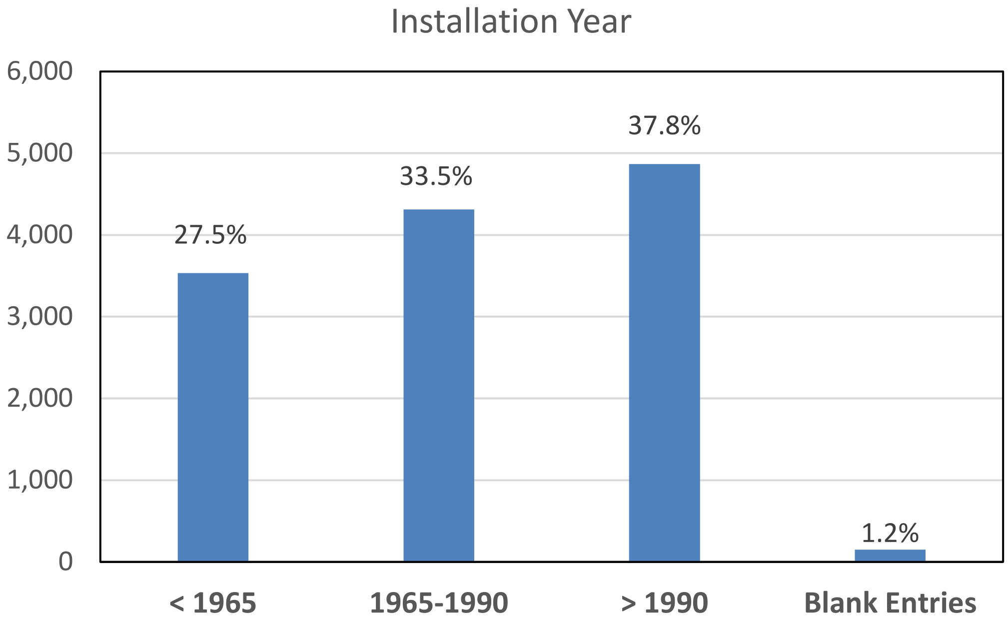


Figure 4. Percentage of Random Sample by Installation Year Categories

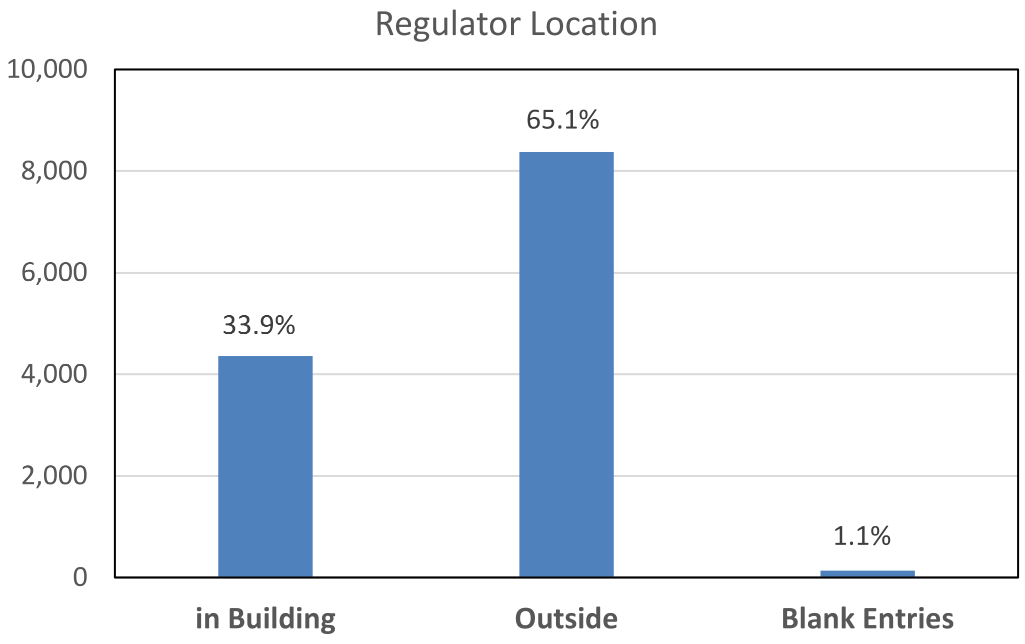


Figure 5. Percentage of Random Sample by Regulator Location Categories

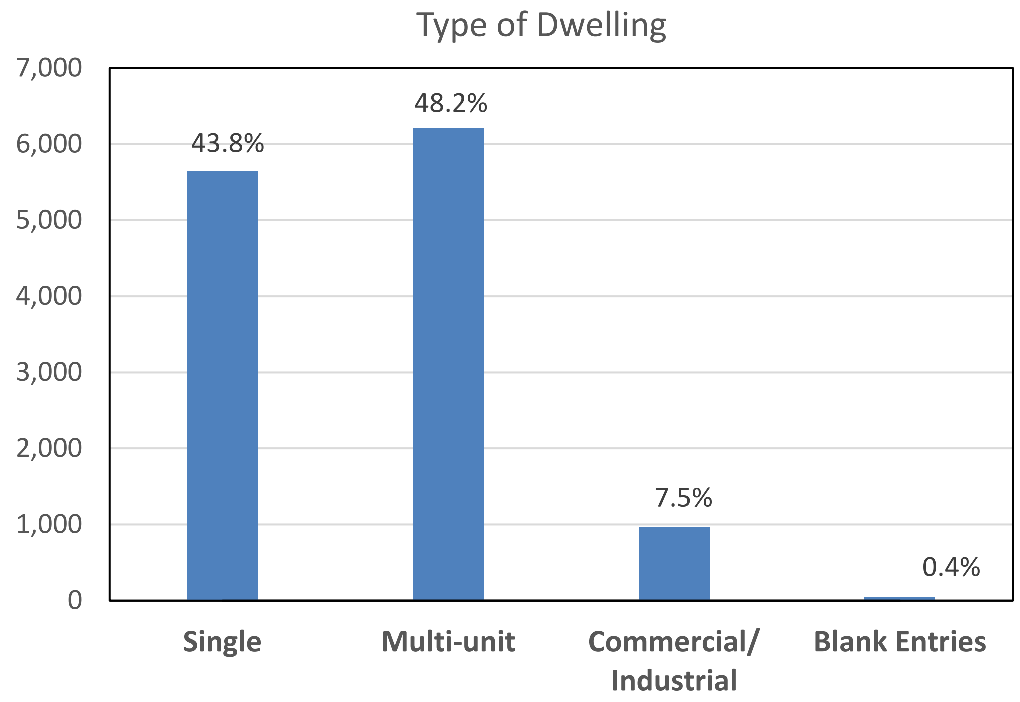


Figure 6. Percentage of Random Sample by Type of Dwelling Categories

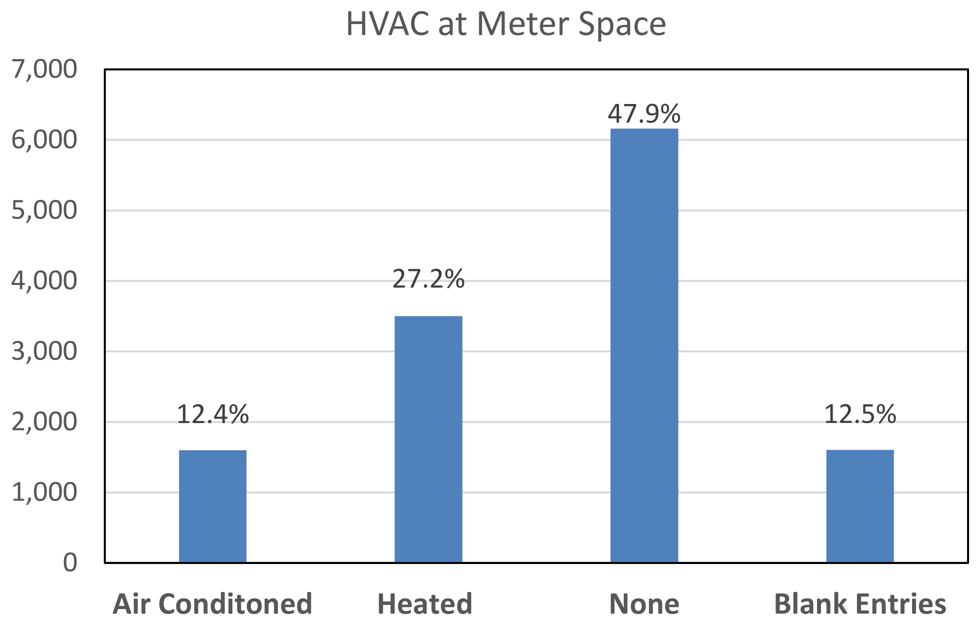


Figure 7. Percentage of Random Sample by HVAC Condition of Meter Space Categories

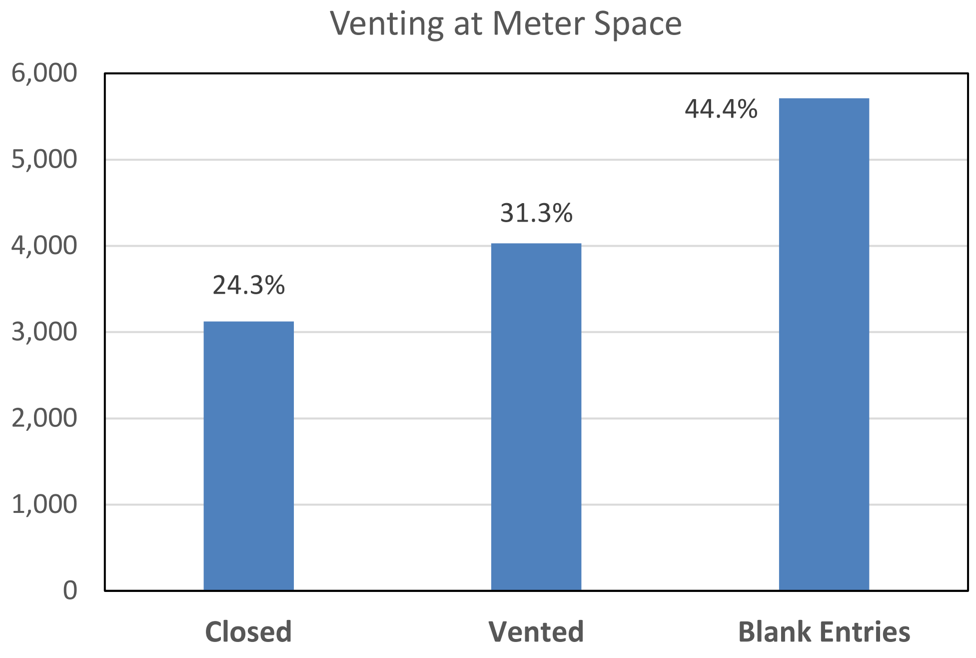


Figure 8. Percentage of Random Sample by Venting at Meter Space Categories

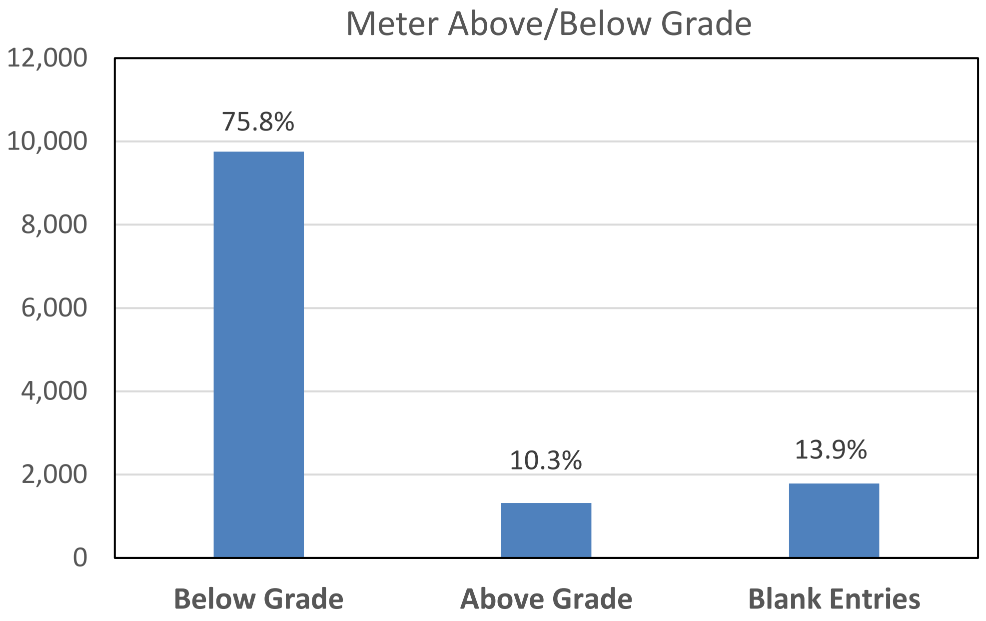
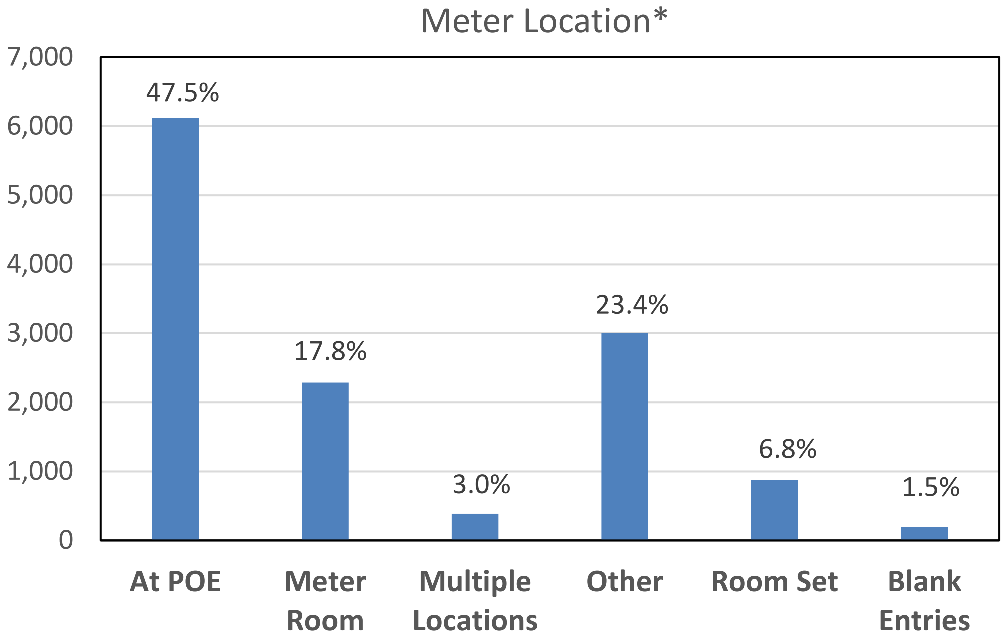


Figure 9. Percentage of Random Sample by Location of Meter to Grade Categories



**Note: "At POE" for "Meter Location" means the indoor meter and associated piping was close to the POE location in the building vs. at a more remote location from the POE. This is different than POE in Figure 3 which notes a survey inspection done on the short section of piping at the building penetration.*

Figure 10. Percentage of Random Sample by Meter Location Categories

The results of the random surveys were analyzed by the variables recorded for each inspection, and showed there were approximately 61% of the sites conditioned and 39% unconditioned; 83% were in urban or rural geographic locations and 17% in coastal or industrial locations; about 54% of the sites were at the building point-of-entry (POE) penetration and for the other 46% of survey sites the meter locations were near the POE in about 48% of the cases; 28% were pre-1965, 34% 1965-1990, and 38% post 1990 installations, 44% were single family dwellings, 48% multi-unit, and 8% commercial or industrial sites.

3.4.2 Two-Variable Groupings Random Sample Program Breakdown

A subset of the key two-factor variable make-up of the sample set is shown in Figure 11 to Figure 14. These two-factor, or bivariate, distributions demonstrate how many samples held two particular categories of two separate variables. For example, Figure 11 shows that the sample set had more significant Conditioned Urban/Rural locations than in Coastal/Industrial locations. Whereas Coastal/Industrial and Non-Conditioned sites were the lowest number of samples in the set.

The bivariate relations can be used in conjunction with the Sensitivity Analysis in a later section of this report to evaluate the effects of the variability of these parameters.

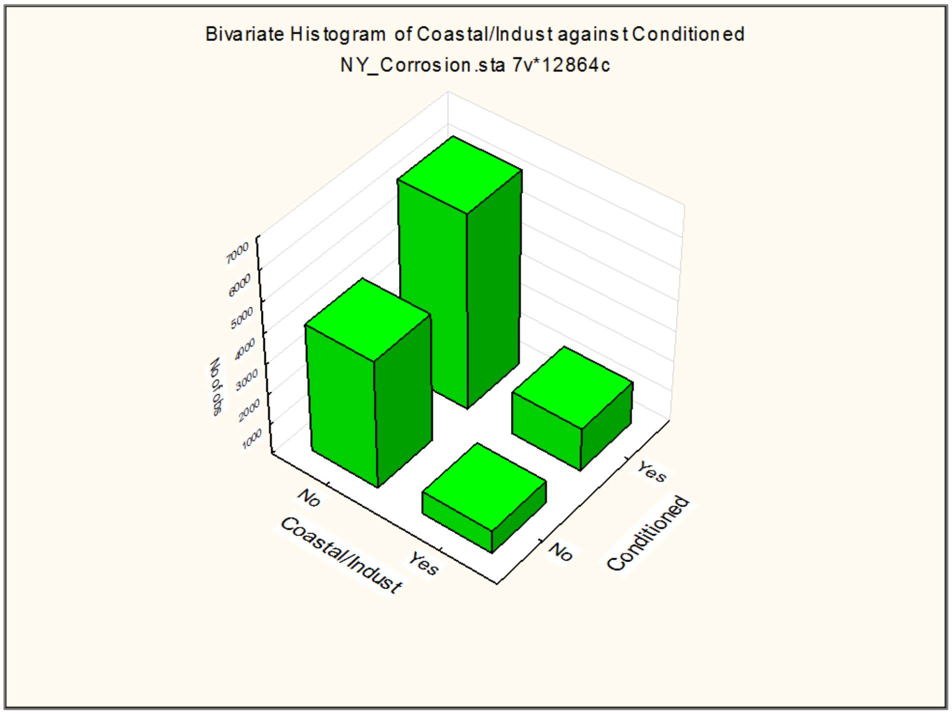


Figure 11. Counts of Sample by Coastal/Industrial vs. Conditioned Variables

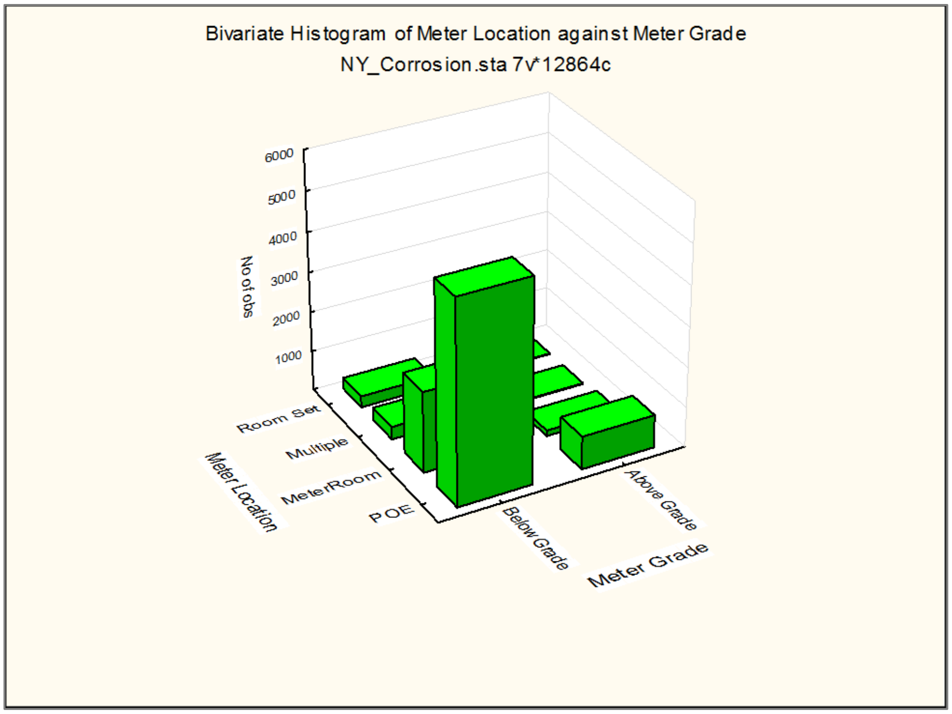


Figure 12. Counts of Sample by Meter Location vs. Meter Grade Categories

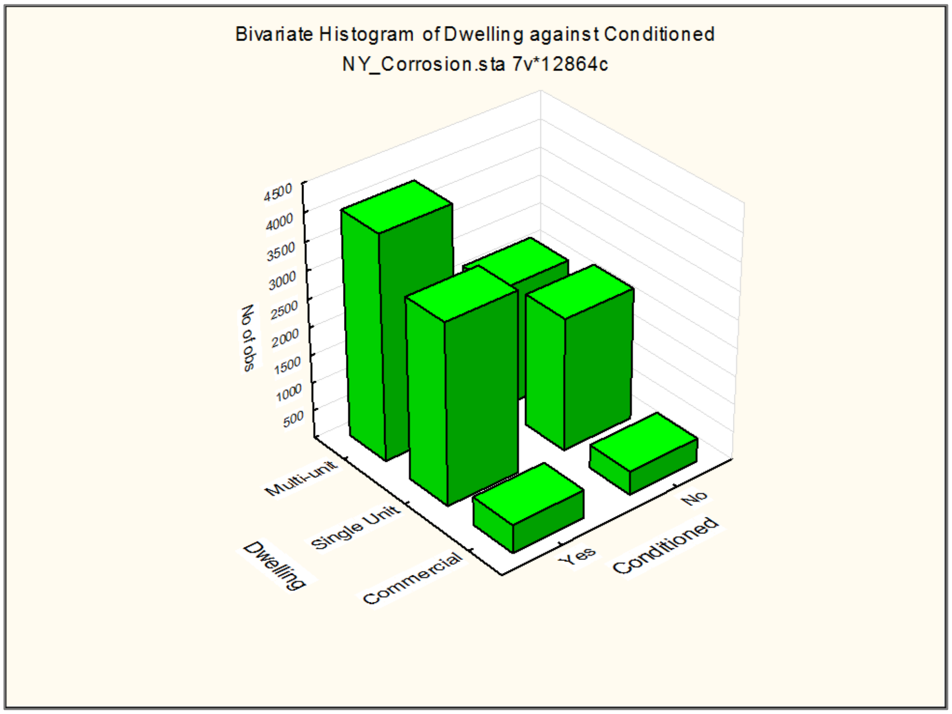


Figure 13. Counts of Sample by Dwelling Type vs. Conditioned Status

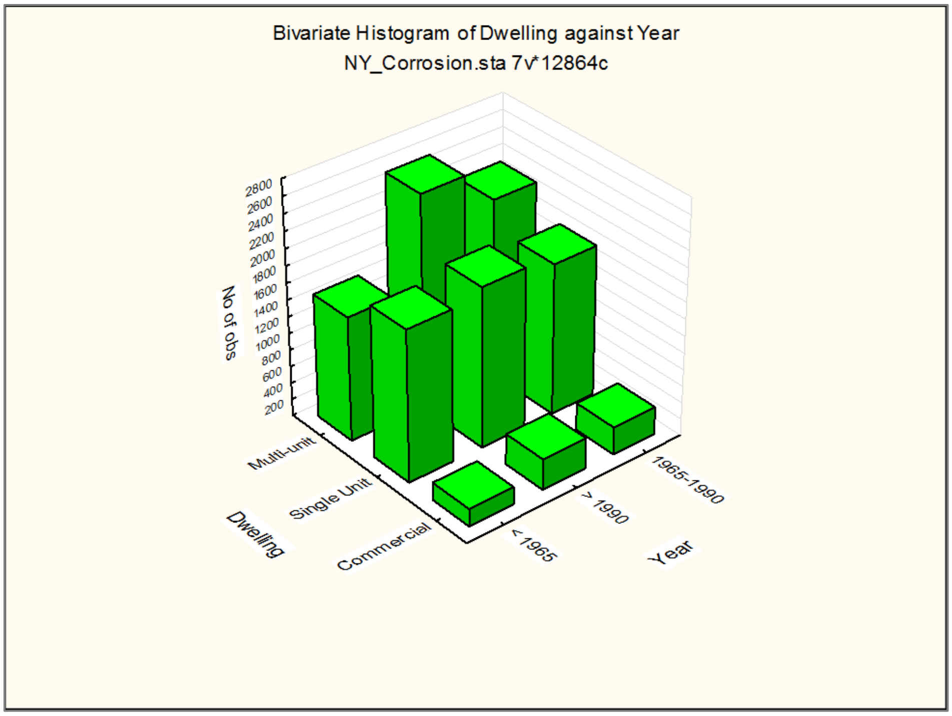


Figure 14. Counts of Sample by Dwelling Type vs. Installation Year

3.5 Descriptive Statistics of Key Operational and Environmental Variables of the Random Sampling Program

3.5.1.1 Spot vs. Continuous Measurements

The random sampling was done in New York State, throughout 2016. This provided a wide range of temperature and relative humidity spot readings distributed throughout the year. Also, since the sample was random, it had the opportunity to include a variety of system pressures depending on the pressure required by the end user of the gas. For corrosion, it would be desirable to know the daily or even hourly temperature and humidity of each location over a one-year cycle, but this is not practical.

3.5.1.2 Temperature and Relative Humidity

By showing the variability of the spot measurements for temperature (Figure 15) and relative humidity (Figure 16), we are able to get the feeling for the environmental range of these variables within the state of New York, as well as the distribution - all where the indoor meters and associated service piping were installed.

The temperature ranged from the 40's to the 90's in °F with the most likely values in the 70s and exhibited a normally distributed behavior.

The relative humidity ranged from the single digit %'s to the 90's % with the most likely values in the 40-50% range and exhibited a normally distributed behavior.

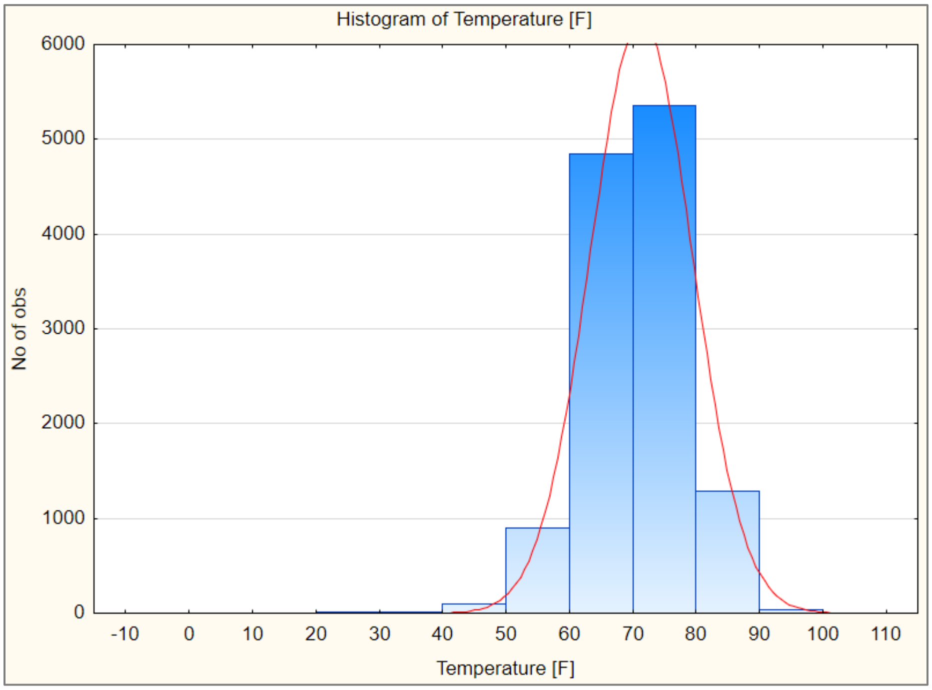


Figure 15. Histogram of Spot Temperature Measurements of Random Sample

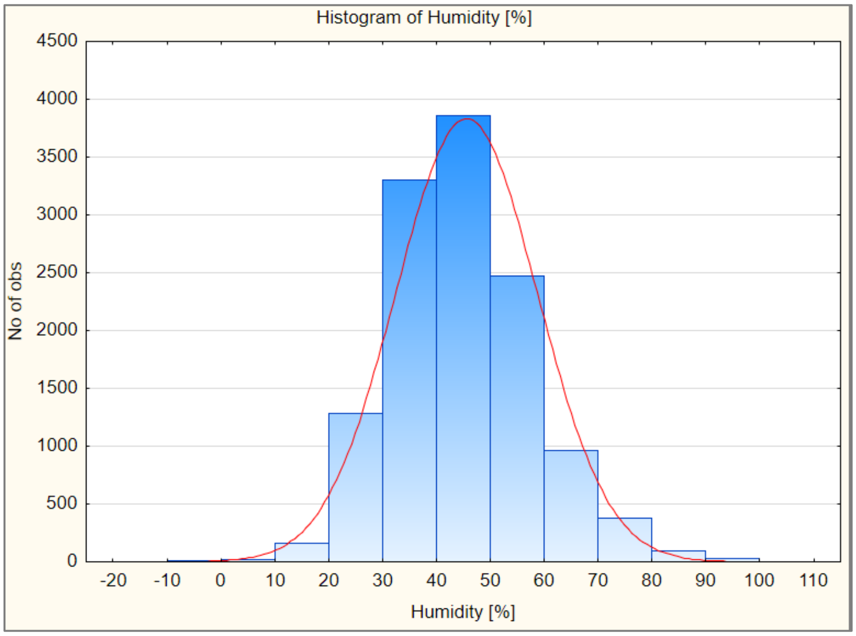


Figure 16. Histogram of Spot Relative Humidity Measurements of Random Sample

3.5.1.3 Pressure Measurements

The pressure variable is a function of the system design and not the environment. The plot is shown in Figure 17 and shows that the pressures ranged from singe or less pig, up to the 150 psig range. More than 85% of the upstream system pressures were less than 60 psig.

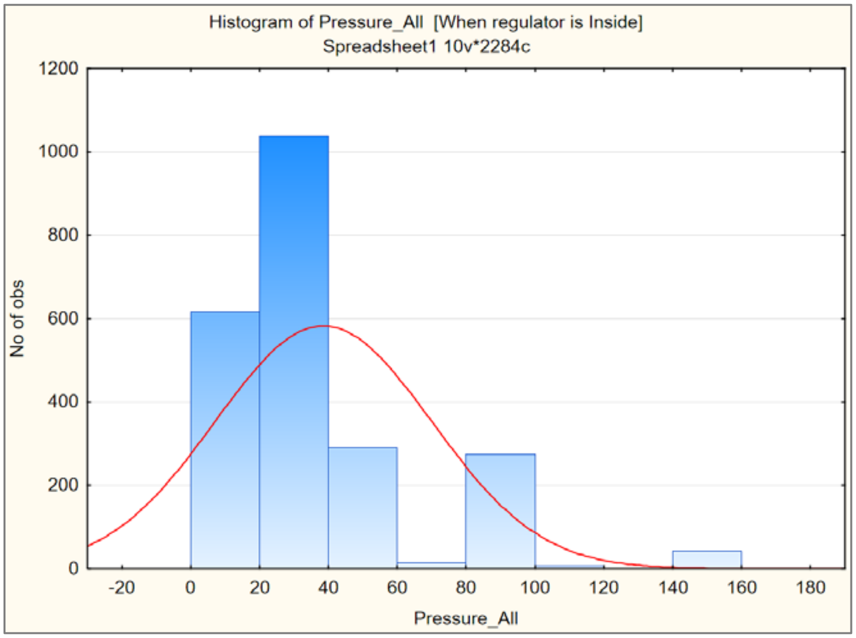


Figure 17. Histogram of System Pressure in Random Sample

4 Random Sampling Program Corrosion and Leak Survey Results

4.1 High-Level, Grouped Analysis of the Random Sampling Program Results

4.1.1 Considerations of Response Results vs. Sample Size

The data sets analyzed in the remainder of the report may not add up to the total values shown in Table 1, since some of the submitted forms had missing data fields. Although this was a small portion of the samples, in some cases we could not classify a sample into a corrosion category or determine if a leak survey was completed and documented. These very limited occurrences were not included in the analysis and did not affect the corrosion or leak indication percentages reported. As noted earlier, the 2,641 samples from New Jersey (PSE&G) are reported in *Appendix B - New Jersey (PSE&G) Limited Data Set and Analysis* of this report.

4.1.2 Leak Threshold and Values

For the sample survey and analysis, a leak indication threshold value of 0.1% Gas was established and was determined by the use of a combustible gas indicator (CGI) per the survey protocol. The basis for this threshold is explained in detail in *Attachment 2 - Leak Survey Equipment Considerations for NY Operations Development of a Regulatory Conformance and Technology Applicability White Paper*.

4.1.3 CGI and Belt Clip Detector Comparison

As part of the survey it was also possible to conduct an ancillary analysis of the use of a belt clip type CGI (no sample probe) in parallel with the conventional handheld CGI utilizing a sample probe. A statistically significant number of leak indications above and below the 0.1% Gas threshold were measured with both the handheld CGI and belt clip CGI and the true/false - positive/negative indications of the belt clip CGI were calculated along with 96% single sided confidence upper and lower limits. The results of this “error” analysis are presented in *Appendix E - Handheld CGI vs. Belt Clip CGI Error Type Comparison* of this report.

4.1.4 Corrosion and Leak High-Level Summary for NY Operators Combined

The high-level summary of New York operator corrosion severity and leak indications is reported in Table 2. The data is cataloged in both numbers of the samples and percent of the overall random sample state-wide. This high-level summary groups all the samples together, regardless of their location (indoor piping meter sets, room sets, building point-of-entry penetration) or which NY operator they came from.

When no value was placed in the CGI column for %Gas and the other fields indicated no leak indications or gas odor, these were classified these as non-leakers. This was confirmed also by discussing with the utilities.

The data in Table 2 is plotted graphically in Figure 18 and Figure 19.

Table 2. Corrosion Inspection Summary for Combined NY Operators

Random Inspection Corrosion and Leak Survey Roll Up	NY Operators Combined	
Corrosion Summary	**Numbers**	**Percent**
None/Minimal Corrosion	10,204	80.67
Low Corrosion	1840	14.55
Med Corrosion	545	4.31
High Corrosion	60	0.47
Sub-Totals	12,649	100.00
Leak Summary	**Numbers**	**Percent**
No Leak Indications	12,478	99.05
Leak Indication (≥ 0.1% Gas on CGI)	120	0.95
Sub-Totals	12,598	100.00

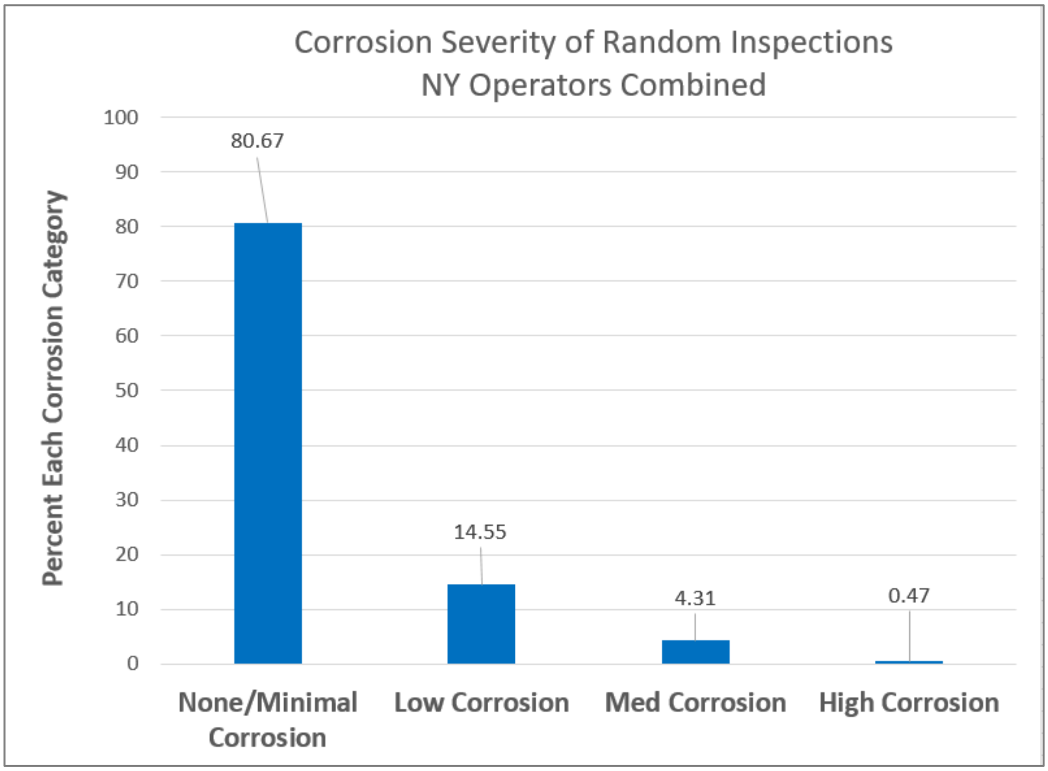


Figure 18. Corrosion Percent by Severity Category for Random Inspections for NY Operators Combined

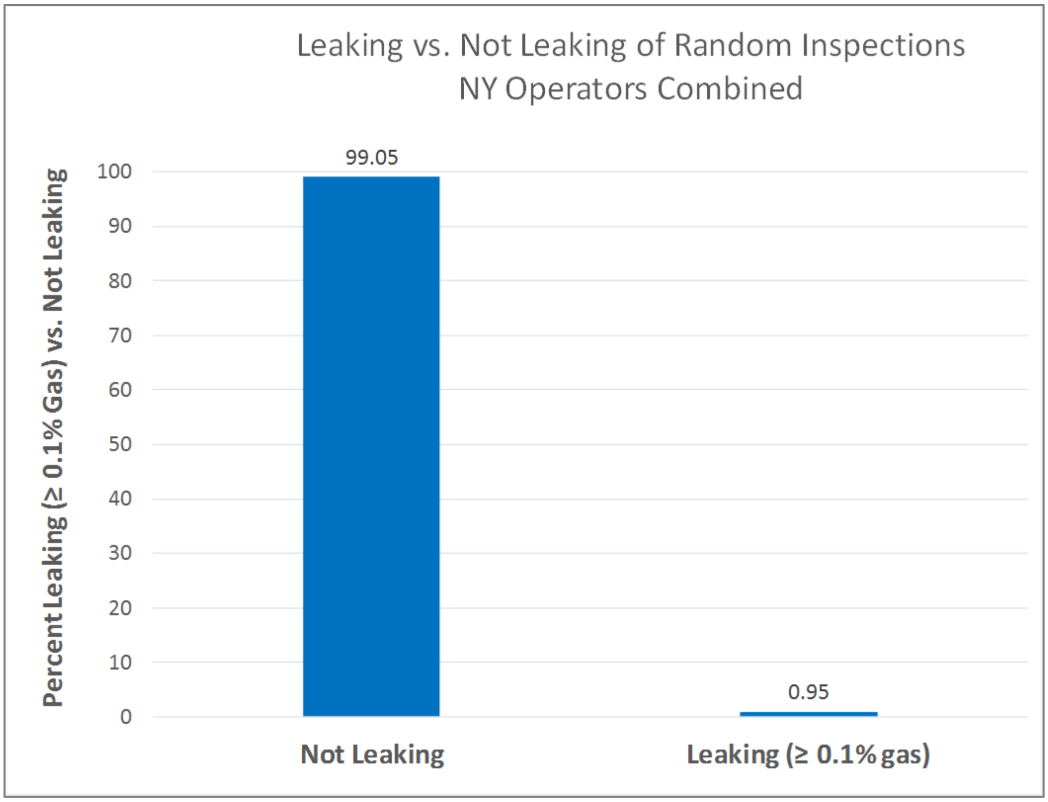


Figure 19. Leak Inspection Summary for NY Operators Combined

4.2 High Level, Combined NY Operators Indoor, Room Sets, and POE Breakdown of Corrosion Severity and Leaks

In this section we still display the survey findings as a combination of NY operators, but we breakdown the survey results by the major inspection location. For completeness we have grouped the NY State results into five groupings:

1. Indoor with room sets and building point of entry (POE) penetration surveys, i.e., all surveys
2. Indoor surveys without room sets or building POE penetration
3. Indoor surveys with room sets
4. Indoor room set surveys only
5. POE surveys only

These five NY groupings of survey results are presented as a tally of counts in Table 3 below and graphically as percentages of corrosion severity levels and leak percentages (of sample sites) per each group in Figure 20 and Figure 21 respectively. We have also included only in Table 3 (not in the figures) the survey results for NY City sites only (header shaded purple).

Table 3. Corrosion and Leak Inspection Summary by Inspection Location for NY Combined Operators

Random Inspection Corrosion and Leak Survey	NY Operators Indoor + Room Sets + POE	NY Indoor (w/out Room Sets)	NY Indoor + Room Sets	NY City Indoor + Room Set	NY Room Sets	NY City Room Set	NY POE	NY City POE
Number of Random Inspections	12,649	4,927	5,752	4075	825	809	6,897	1726
Corrosion Summary								
None/Minimal Corrosion	10,204	4,103	4,784	3381	681	669	5,420	1337
Low Corrosion	1840	642	769	585	127	126	1071	336
Med Corrosion	545	172	187	104	15	12	358	42
High Corrosion	60	10	12	5	2	2	48	11
Leak Summary								
Not Leaking	12,478	4,920	5,741	4074	821	809	6,737	1723
Leaking (≥ 0.1% Gas)	120	10	16	1	6	0	104	3
Percent Leaking (≥ 0.1% Gas)	0.95%	0.20%	0.28%	0.0245%	0.73%	0.000%	1.52%	0.174%

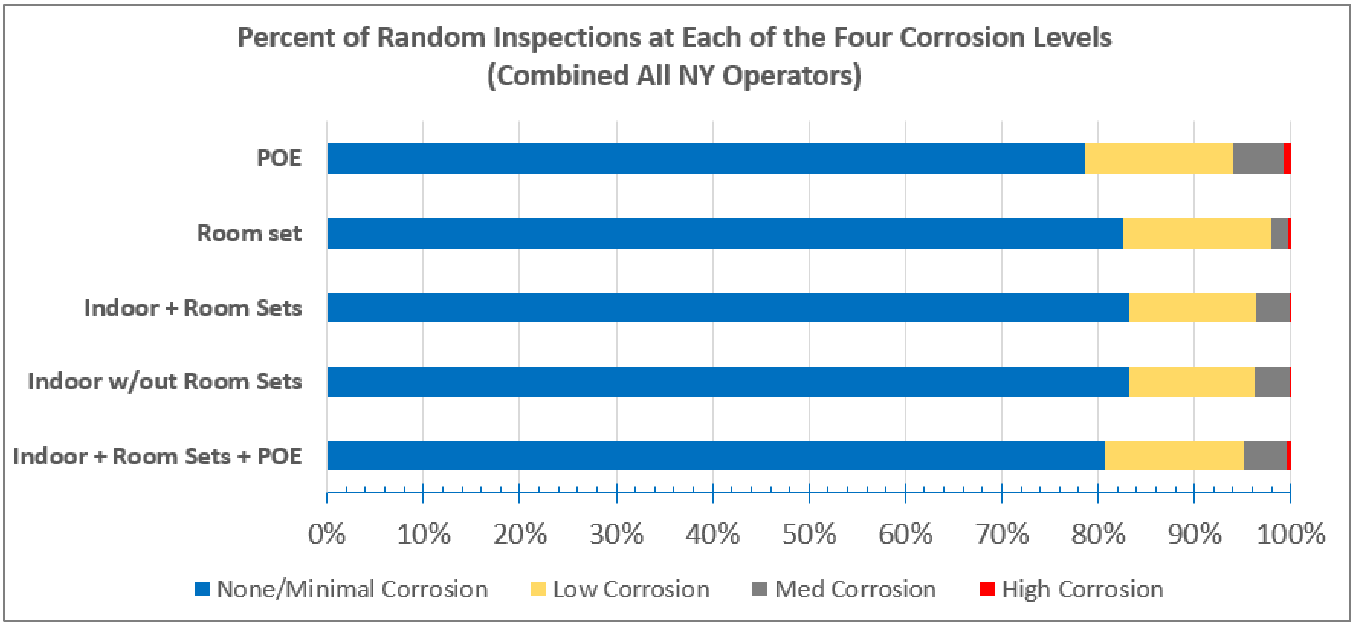


Figure 20. Corrosion Category Percentages by Inspection Location for NY Combined

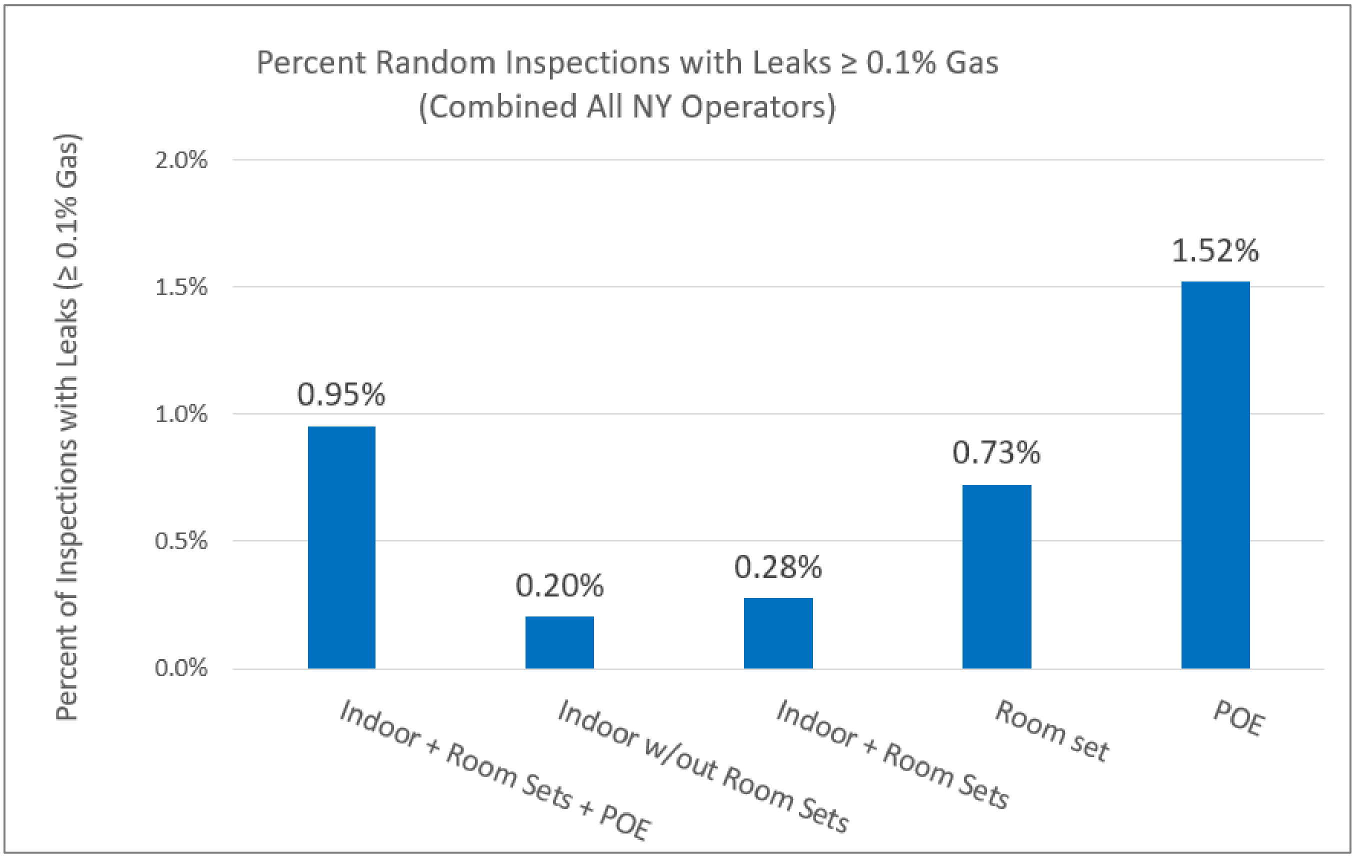


Figure 21. Leak Percentages of Random Inspection Sites by Inspection Location for NY Combined

4.3 Breakdown Analysis of Random Sample Set Results by Individual Operators

In this section we have broken down the sample results for corrosion severity and leaks by NY operator and into two further sub-groupings:

1. Indoor with Room Set Surveys - Table 4 and graphically in Figure 22 to Figure 24
2. Building Point of Entry (POE) Penetration Surveys - Table 5 and graphically in Figure 25 to Figure 27

We also subdivided the survey results in each of the two main groupings by NY operator (and included the combined value as well).

Table 4. Corrosion and Leak Inspection Summary by NY Operator and Combined for Indoor + Room Sets

Indoor + Room Sets **Random Inspection Corrosion and Leak Survey Roll Up**	**NY Combined**	NGrid	ConEd	NYSEG	NFuel	Cent Hud	RGE	O&R	St Lawrence
Samples w/Adequate Data Fields	5,752	2,777	2,227	255	89	32	292	61	19
Corrosion Summary									
None/Minimal Corrosion	4,784	2,267	1,838	251	74	18	284	35	17
Low Corrosion	769	329	389	1	7	10	6	25	2
Med Corrosion	187	172	0	3	5	4	2	1	0
High Corrosion	12	9	0	0	3	0	0	0	0
Leak Summary									
Samples w/Adequate Data Fields	5,757	2,781	2,227	255	90	32	292	61	19
No Leak Indication	5,741	2,765	2,227	255	90	32	292	61	19
Leak Indication (≥ 0.1% Gas)	16	16	0	0	0	0	0	0	0
Percent of Leak Indications (≥ 0.1% Gas)	0.3%	0.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

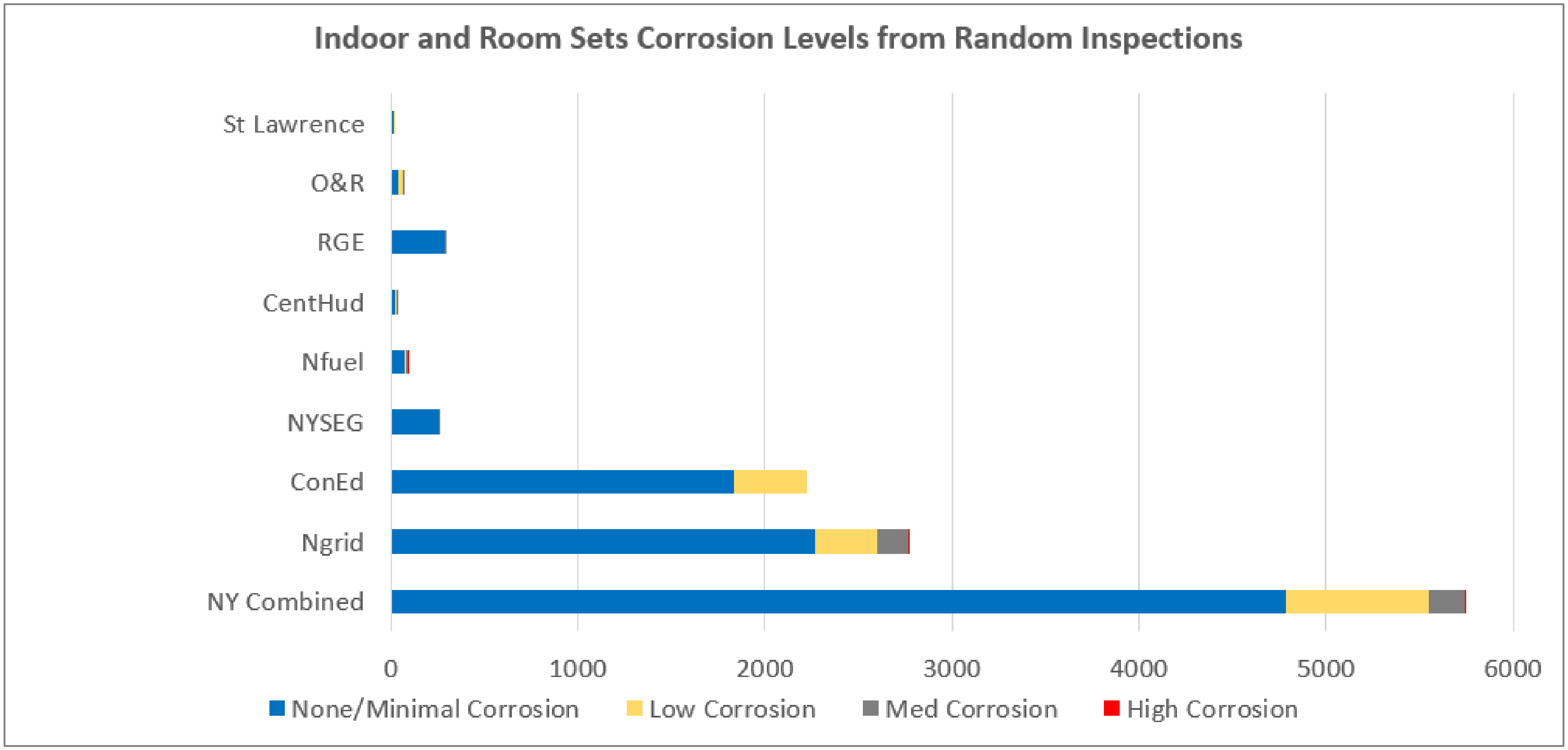


Figure 22. Absolute Count of Corrosion Severity Levels for Indoor + Room Set Inspection Sites by NY Operator and Combined

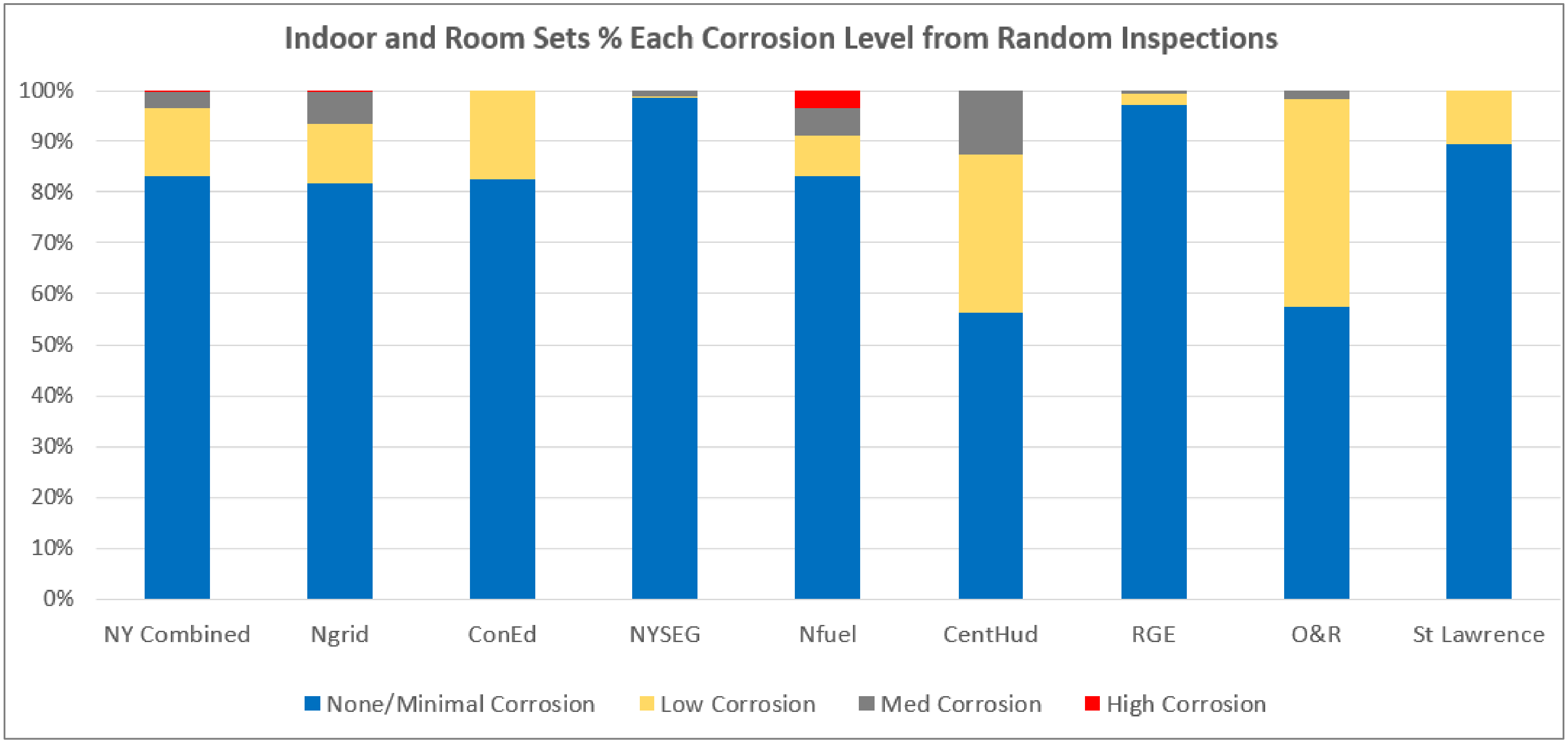
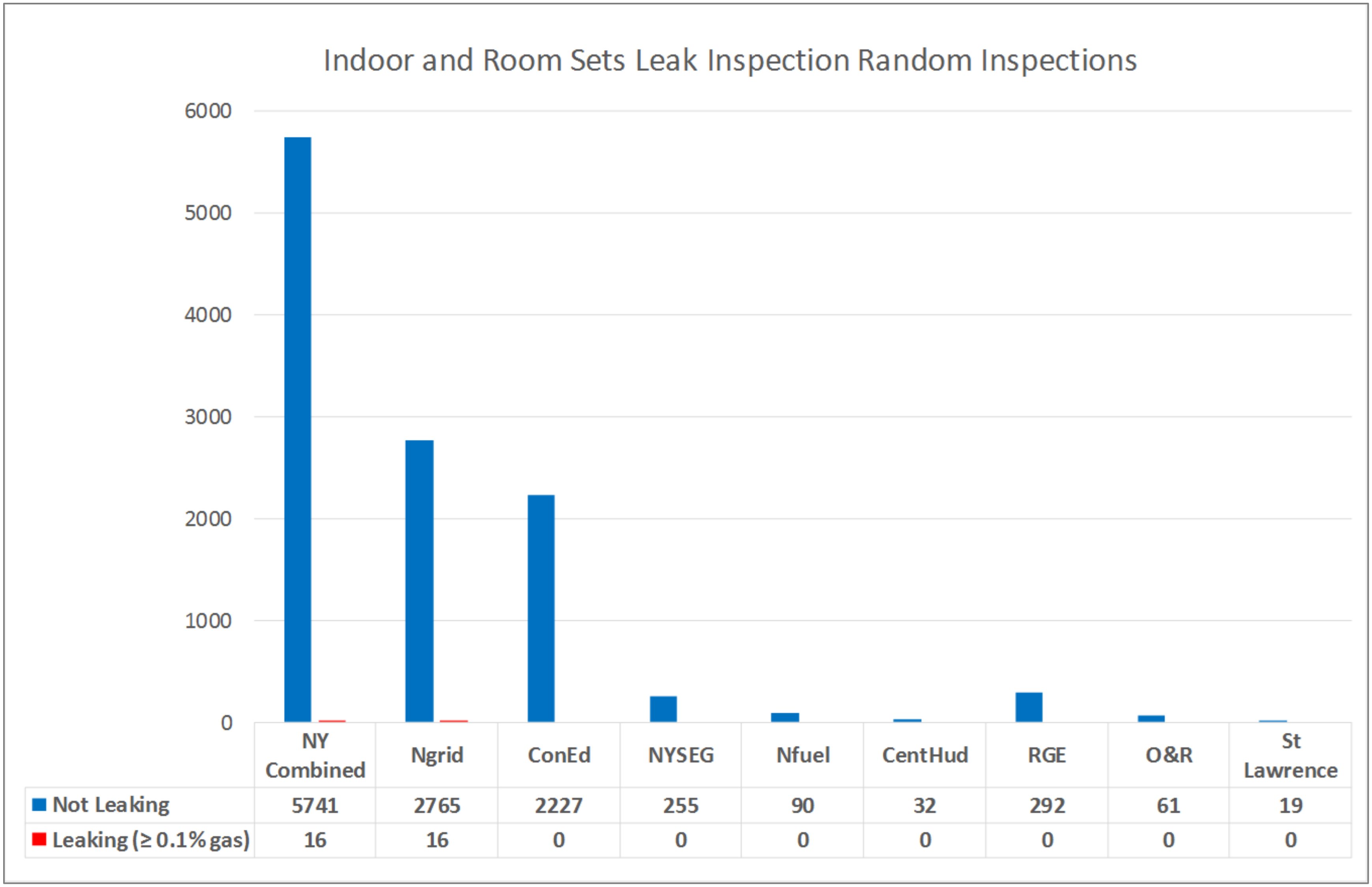


Figure 23. Corrosion Severity Level % by NY Operator and Combined for Indoor + Room Set Inspection Sites



	NY Combined	Ngrid	ConEd	NYSEG	Nfuel	CentHud	RGE	O&R	St Lawrence
🟦 Not Leaking	5741	2765	2227	255	90	32	292	61	19
🟥 Leaking (≥ 0.1% gas)	16	16	0	0	0	0	0	0	0

Figure 24. Absolute Count of Leaks for Indoor + Room Set Inspection Sites by NY Operator and Combined

Table 5. Corrosion and Leak Inspection Summary by NY Operator and Combined for Building POE Penetration Sites

Building Point of Entry (POE) Penetrations **Random Inspection Corrosion and Leak Survey Roll Up**	**NY Combined**	NGrid	ConEd	NYSEG	NFuel	CentHud	RGE	O&R	St Lawrence
Samples w/Adequate Data Fields	6,897	5,397	769	256	86	32	292	60	5
Corrosion Summary									
None/Minimal Corrosion	5,420	4,196	563	252	70	19	283	34	3
Low Corrosion	1,071	817	204	1	7	9	6	25	2
Med Corrosion	358	340	2	2	6	4	3	1	0
High Corrosion	48	44	0	1	3	0	0	0	0
Leak Summary									
Samples w/Adequate Data Fields	6,841	5,339	769	256	88	32	292	60	5
No Leak Indication	6,737	5,239	766	256	87	32	292	60	5
Leak Indication (≥ 0.1% Gas)	104	100	3	0	1	0	0	0	0
Percent of Leak Indications (≥ 0.1% Gas)	1.5%	1.9%	0.4%	0.0%	1.1%	0.0%	0.0%	0.0%	0.0%

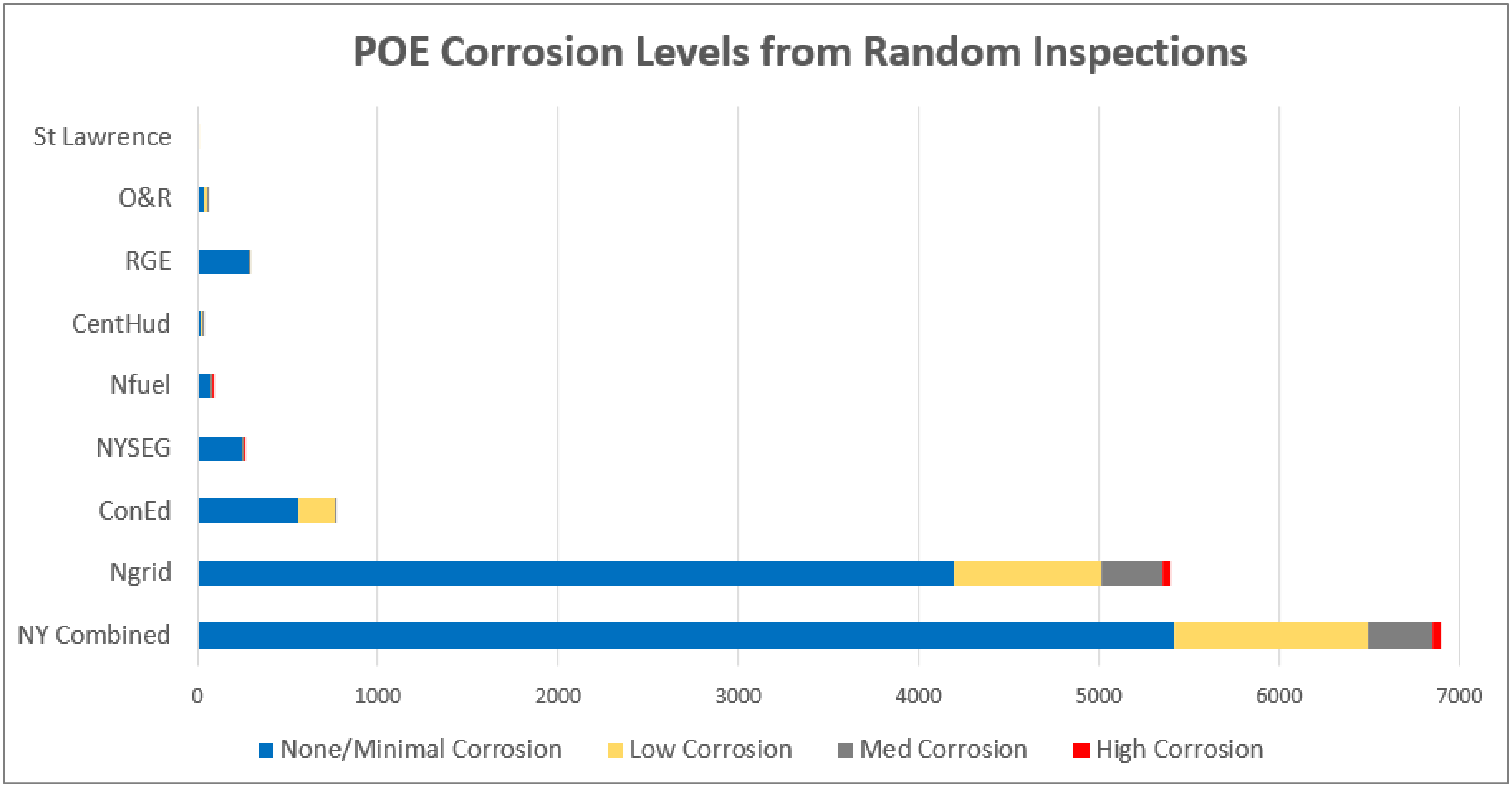


Figure 25. Absolute Count of Corrosion Severity Levels for POE Inspection Sites by NY Operator and Combined

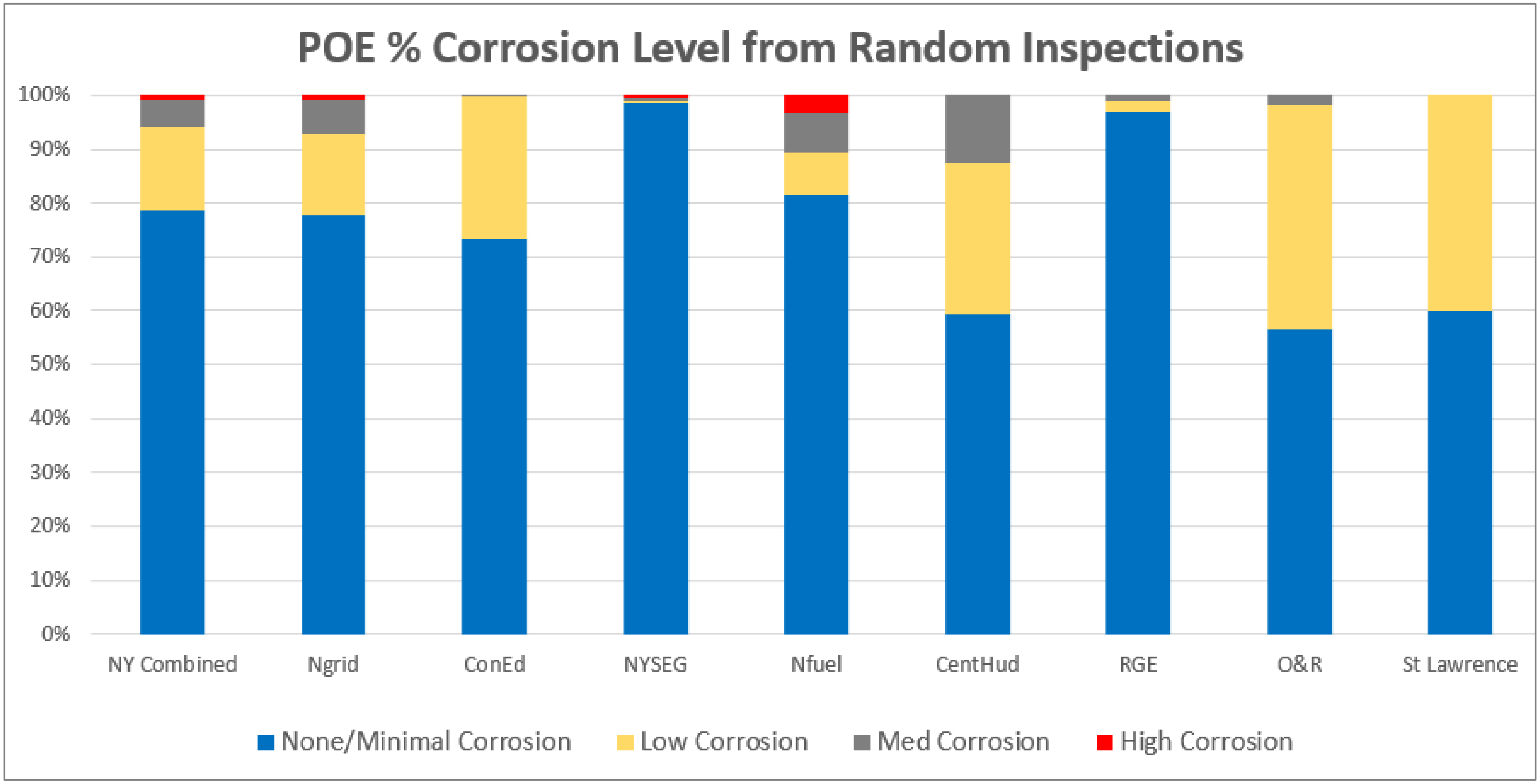
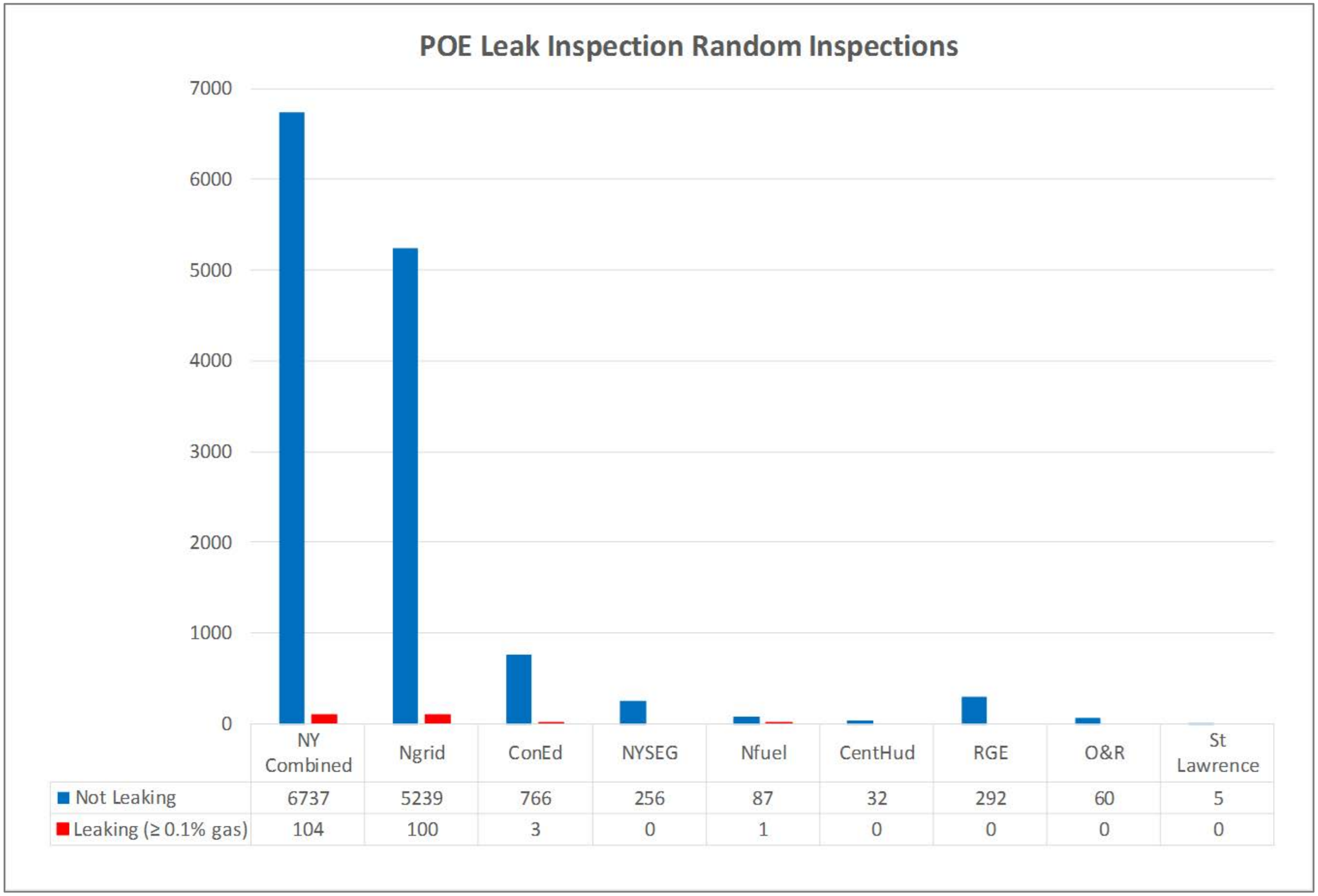


Figure 26. Corrosion Severity Level % by NY Operator and Combined for POE Inspection Sites



	NY Combined	Ngrid	ConEd	NYSEG	Nfuel	CentHud	RGE	O&R	St Lawrence
🟦 Not Leaking	6737	5239	766	256	87	32	292	60	5
🟥 Leaking (≥ 0.1% gas)	104	100	3	0	1	0	0	0	0

Figure 27. Absolute Count of Leaks for POE Inspection Sites by NY Operator and Combined

4.4 New York City (NYC) Only - Operators Indoor, Room Sets, and POE Breakdown of Corrosion Severity and Leaks

The random survey data for New York City (NYC) only locations is presented in this section and has the same format as the NY Statewide data presented in the previous section.

In this section we have broken down the sample results for corrosion severity and leaks by NY City operator (and combined) and into two further sub-groupings:

1. Indoor with Room Set Surveys - Table 6 and graphically in Figure 28 to Figure 30
2. Building Point of Entry (POE) Penetration Surveys - Table 7 and graphically in Figure 31 to Figure 33.

Table 6. Corrosion and Leak Inspection Summary for NY City Samples by NY City Operator and Combined for Indoor + Room Sets

Indoor + Room Sets **Random Inspection Corrosion and Leak Survey Roll Up**	**NGrid NYC**	**ConEd NYC**	**Combined NYC**
Corrosion Summary			
Samples w/Adequate Data Fields	1848	2227	4075
None/Minimal Corrosion	1543	1838	3381
Low Corrosion	196	389	585
Med Corrosion	104	0	104
High Corrosion	5	0	5
Leak Summary			
Samples w/Adequate Data Fields	1848	2227	4075
No Leak Indication	1847	2227	4074
Leak Indication (≥ 0.1% Gas)	1	0	1
Percent of Leak Indications (≥ 0.1% Gas)	0.054%	0.000%	0.0245%

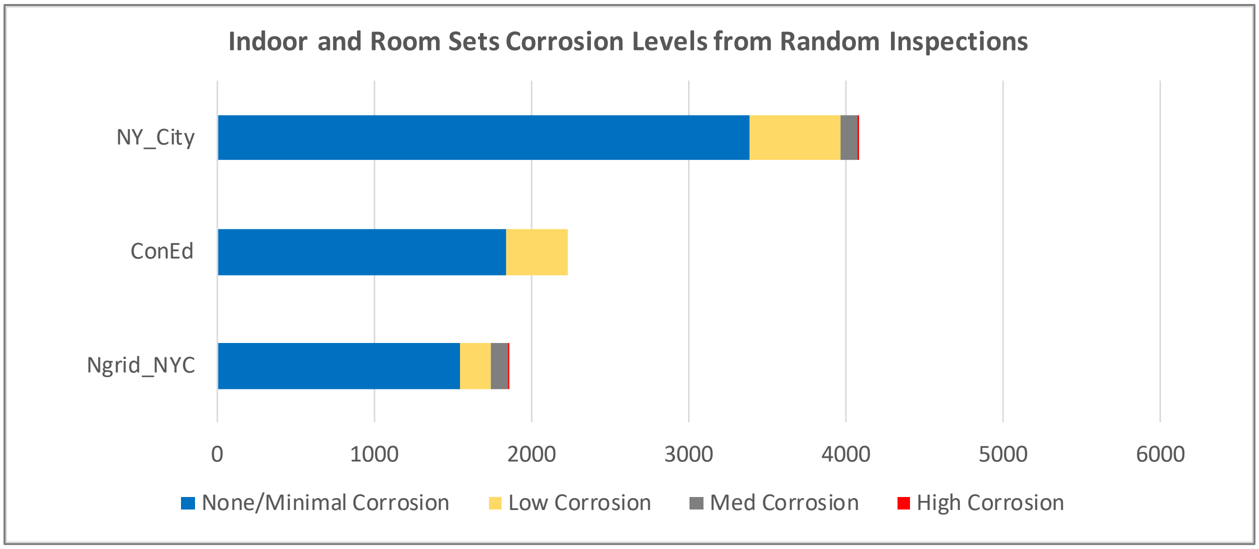


Figure 28. Absolute Count of Corrosion Severity Levels for Indoor + Room Set Inspection Sites by NY City Operator and Combined

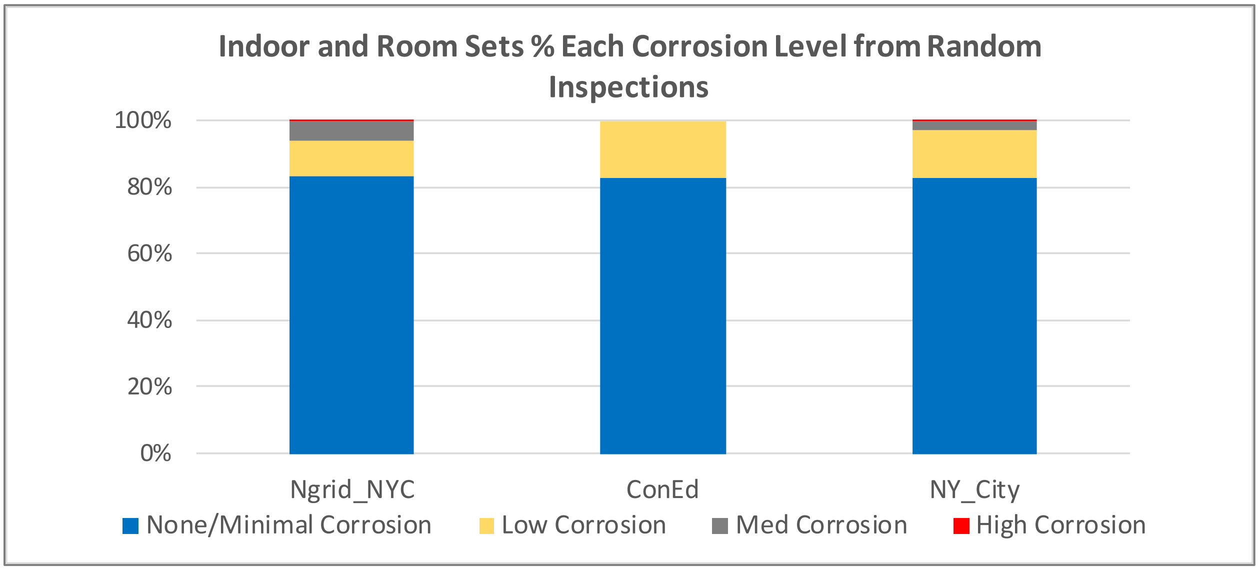


Figure 29. Corrosion Severity Level % by NY City Operator and Combined for Indoor + Room Set Inspection Sites

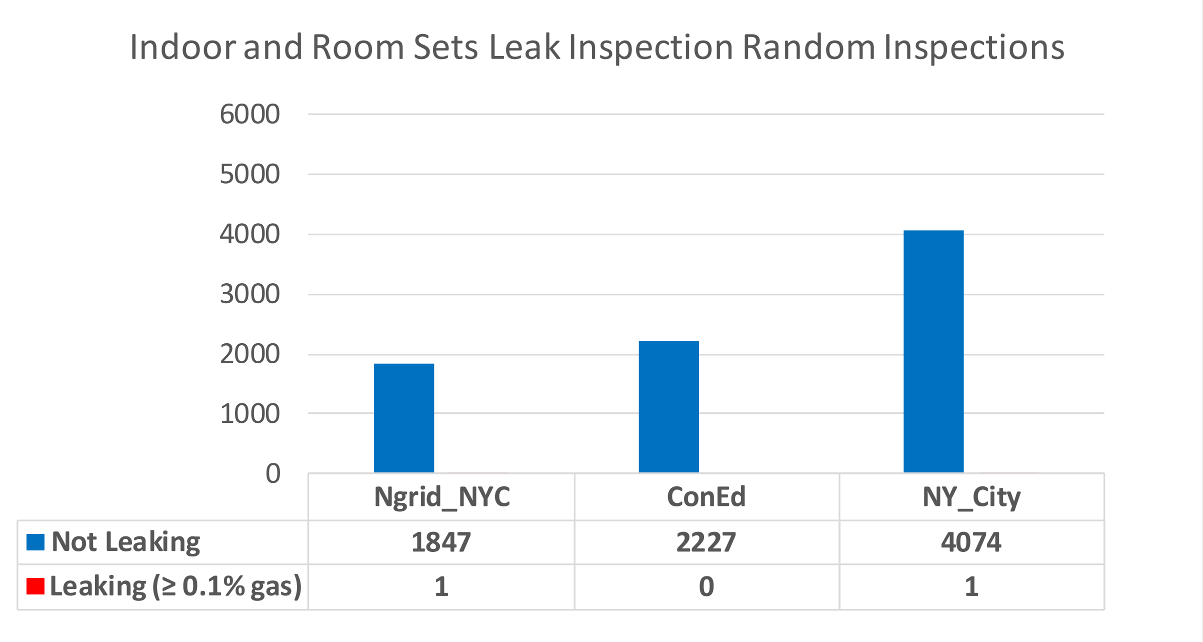


Figure 30. Absolute Count of Leaks for Indoor + Room Set Inspection Sites by NY City Operator and Combined

Table 7. Corrosion and Leak Inspection Summary by NY City Operator and Combined for Building POE Penetration Sites

Building Point of Entry (POE) Penetrations **Random Inspection Corrosion and Leak Survey Roll Up**	**NGrid NYC**	**ConEd NYC**	**Combined NYC**
Corrosion Summary			
Samples w/Adequate Data Fields	958	769	1,727
None/Minimal Corrosion	774	563	1,337
Low Corrosion	132	204	336
Med Corrosion	40	2	42
High Corrosion	11	0	11
Leak Summary			
Samples w/Adequate Data Fields	957	769	1,726
No Leak Indication	957	766	1,723
Leak Indication (≥ 0.1% Gas)	0	3	3
Percent of Leak Indications (≥ 0.1% Gas)	0.000%	0.40%	0.17%

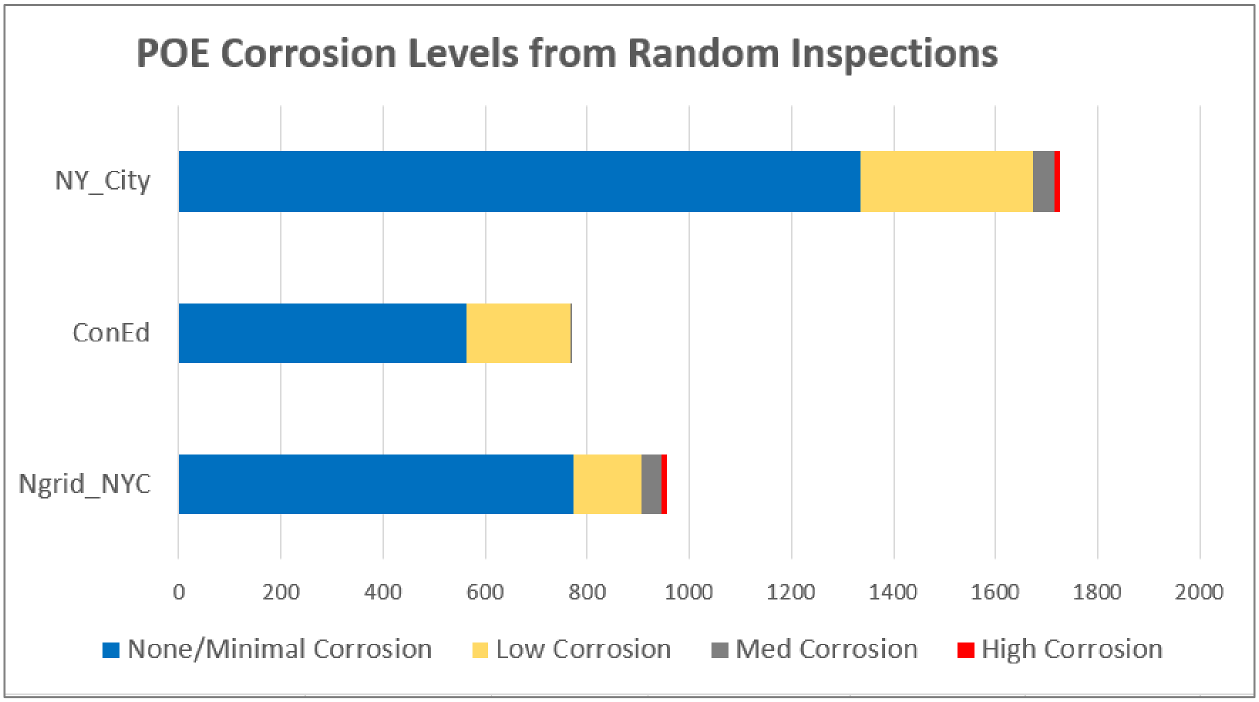


Figure 31. Absolute Count of Corrosion Severity Levels for POE Inspection Sites by NY City Operator and Combined

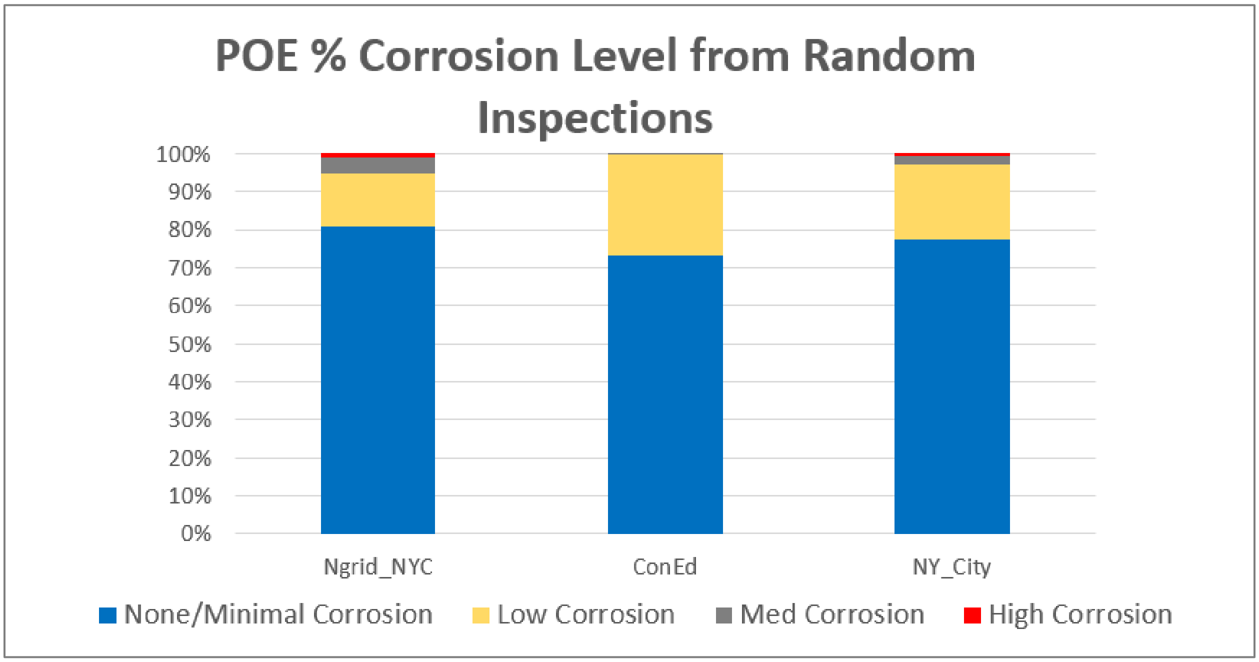
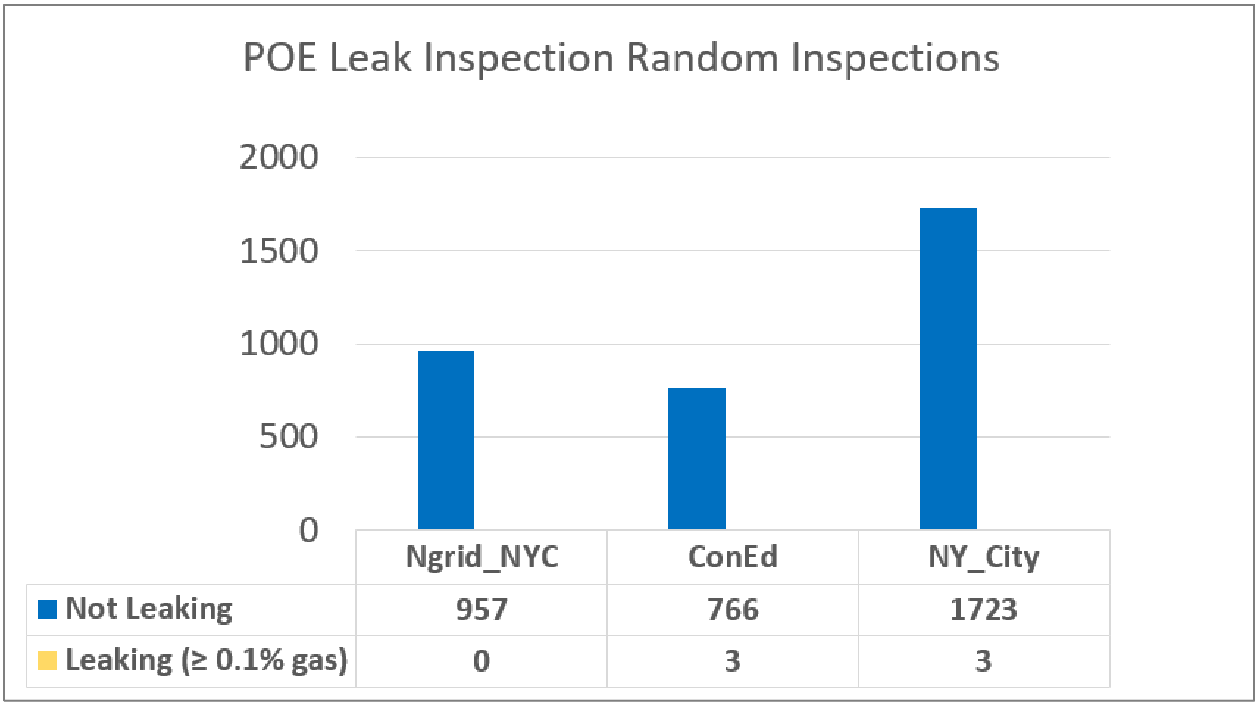


Figure 32. Corrosion Severity Level % by NY City Operator and Combined for POE Inspection Sites



	Ngrid_NYC	ConEd	NY_City
🟦 Not Leaking	957	766	1723
🟨 Leaking (≥ 0.1% gas)	0	3	3

Figure 33. Absolute Count of Leaks for POE Inspection Sites by NY City Operator and Combined

5 Corrosion Severity and Leaks as a Function of Environmental and Operational Variables - Statistical and Regression Analysis

This section provides a sensitivity analysis of the sample variables versus the corrosion severity and leak indications. The corrosion severity analysis is presented first followed by the leak data analysis. Since the corrosion severity response was a categorical variable (with four levels) we have created several variability plots to show the presence, or lack of, specific corrosion severity levels in various combinations of sample variable categories. Both the corrosion severity and leak analysis include the analysis of means plots that correlate the various variable categories to the observed corrosion severity and leaks.

A variable sensitivity analysis was conducted to determine what variables correlated to increased corrosion severity and leaks observed. The categorical levels for corrosion and leaks were assigned an ordinal number that was used to calculate average values for corrosion and leak indexes. A comparison of means (averages) was conducted for each variable category to determine if there was a statistical difference between it and the remaining categories for the variable. This was supplemented with an analysis of variation (ANOVA) regression analysis to confirm the significant variables (inclusive of all categories) as related to the corrosion and leak findings.

5.1 Corrosion Sensitivity Analysis - Severity as a Function of Variables

5.1.1 Variability of Response Categories for Corrosion Severity

The variability plots shown in Figure 34 to Figure 37 provide a quick indication of which variable category combinations have at least one survey location with the various corrosion severities.

The corrosion severity was assigned whole numbers as follows:

1)	None/Minimal Corrosion	*1*
2)	Low Corrosion Severity	*2*
3)	Medium Corrosion Severity	*3*
4)	High Corrosion Severity	*4*

For example, Figure 34 plots two variables (a) *Meter Grade* (above or below grade), and (b) *Location* (at POE, Meter Room, Multiple, or Room Set) combinations along the horizontal axis; the *Corrosion Severity* levels (1, 2, 3, and 4) are plotted on the vertical axis. If there was at least one survey site that had the stated corrosion severity then a triangle (raw data) would be present. The variable combinations are boxed in blue, red, and green to show overall trends.

One could summarize this figure as follows:

1) Below Grade locations exhibited all ranges of corrosion from none/minimal to high

2) Above Grade locations exhibited all ranges of corrosion from none/minimal to high
3) Above Grade samples with the meter and piping at or near the POE exhibited all ranges of corrosion from none/minimal to high
4) Above Grade, Meter Room locations exhibited corrosion from none/minimal to medium, but not high
5) Above Grade, Multiple Meter Locations exhibited corrosion only in the none/minimal and medium severities, but not in the low and high
6) Above Grade Room Sets exhibited corrosion only in none/minimal and low, and not in medium or high

The other variability plots can be analyzed the same way.

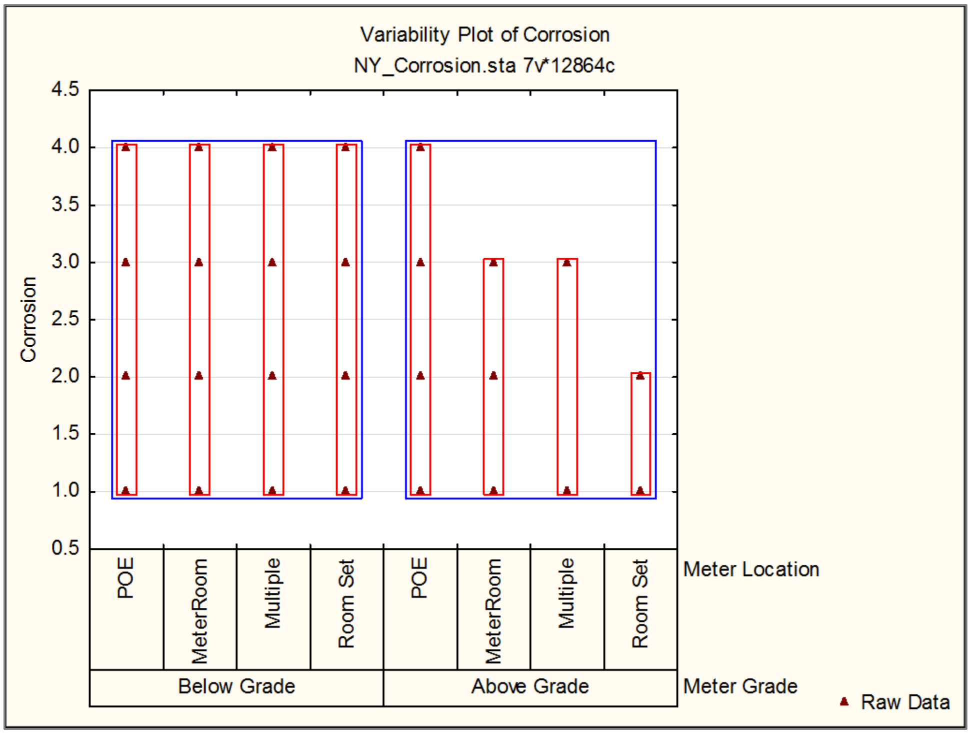


Figure 34. Variability Plot of Corrosion Severity Existence by Grade Location and Meter Location

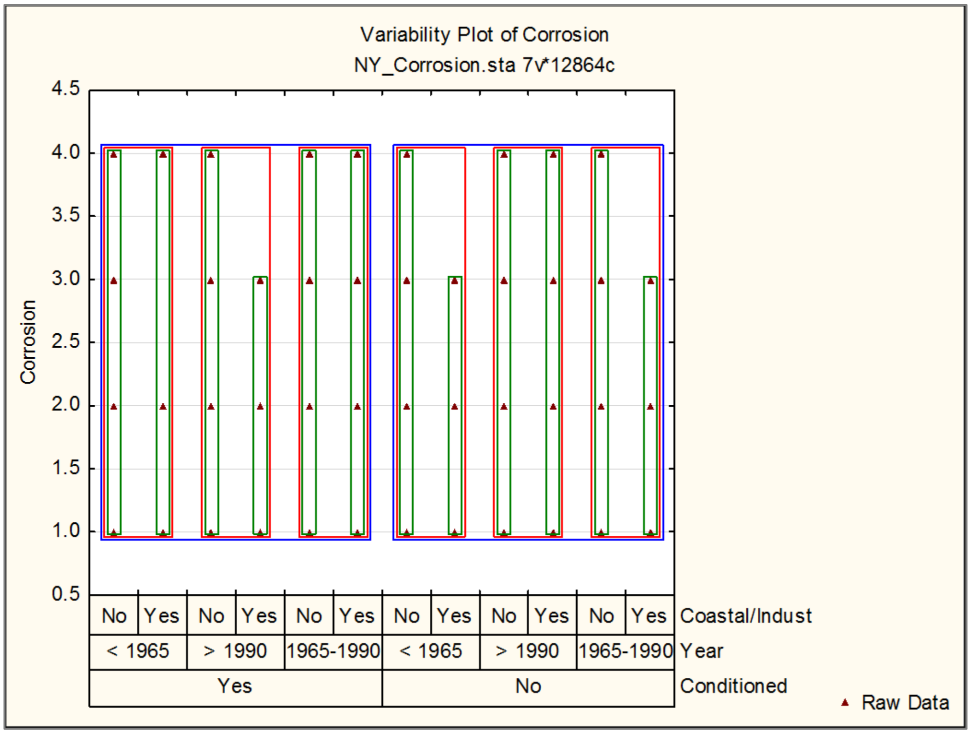


Figure 35. Variability Plot of Corrosion Severity Existence by Conditioning Status, Installation Year, and Coastal/Industrial vs. Urban/Rural Locations

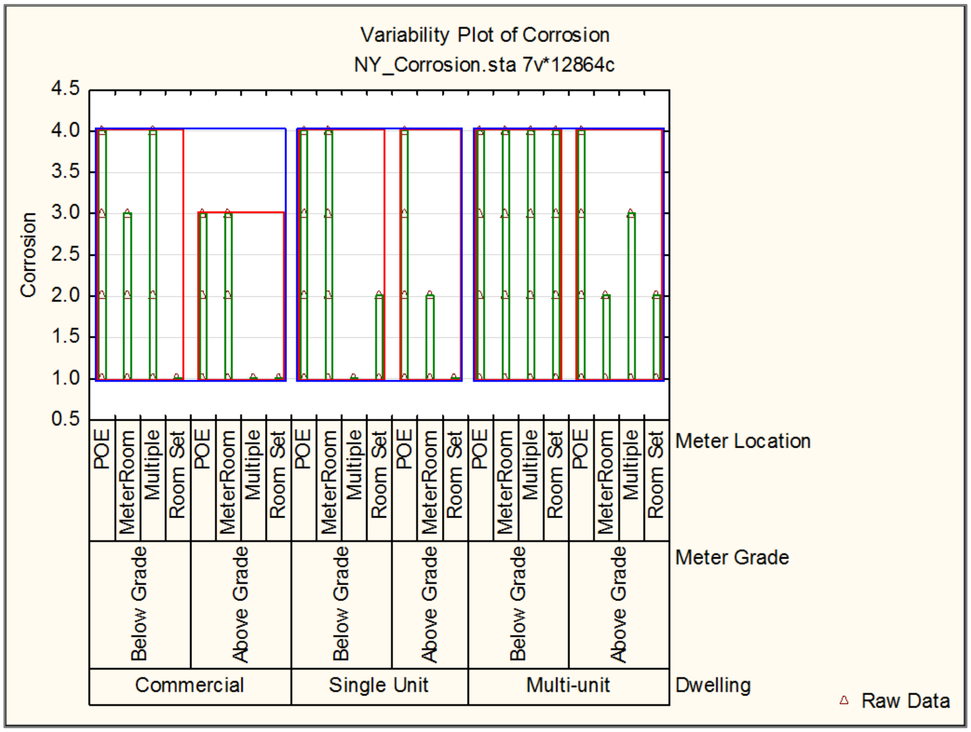


Figure 36. Variability Plot of Corrosion Severity Existence by Dwelling Type, Meter Grade, and Meter Location

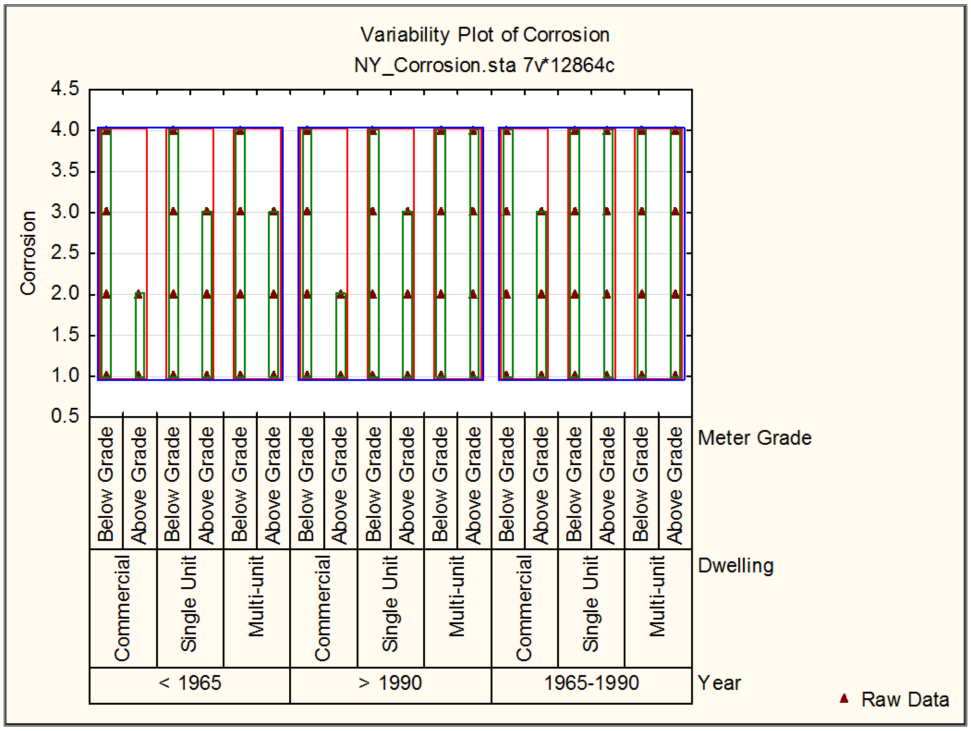


Figure 37. Variability Plot of Corrosion Severity Existence by Installation Year, Dwelling Type, and Meter Grade

5.1.2 Analysis of Means for Corrosion Severity

The same data can be summarized in a different format, where one averages the corrosion severity from 1.0 to 4.0 for a single variable and plots the average with 95% confidence intervals for each category under the variable.

These plots are shown in Figure 38 to Figure 43. These address the six primary variables of the sample set.

- Space conditioning
- Geographic location
- Installation year
- Meter location to grade
- Dwelling type
- Meter location

For example, Figure 38 exhibits the average corrosion severity for Conditioned vs. Non-Conditioned locations; with Conditioned at a corrosion index of about 1.19 and Non-Conditioned at about 1.33. Meaning on average, the Non-Conditioned spaces had a corrosion severity about 12% higher (on an index from 1.0 to 4.0) than Conditioned.

The confidence interval (95%) around the average corrosion severities for the variable categories do not overlap. This is a good indication that the groups are statistically separate, or put another way, that the difference of the averages is not attributed to random variation of the samples.

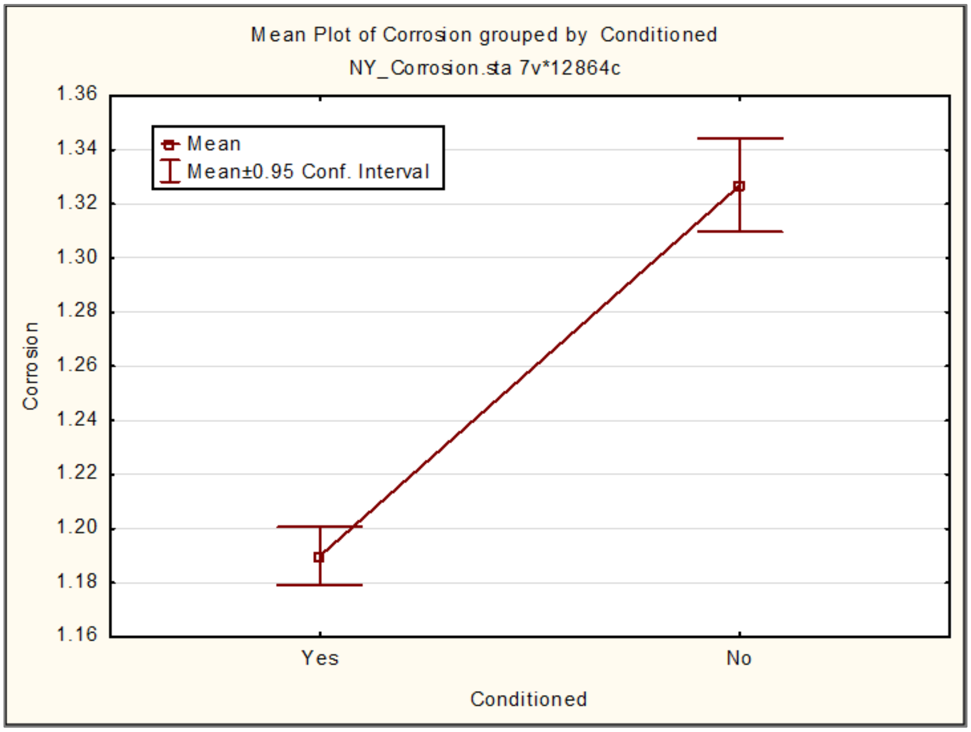


Figure 38. Mean Plot of Corrosion Severity vs. Space Conditioning

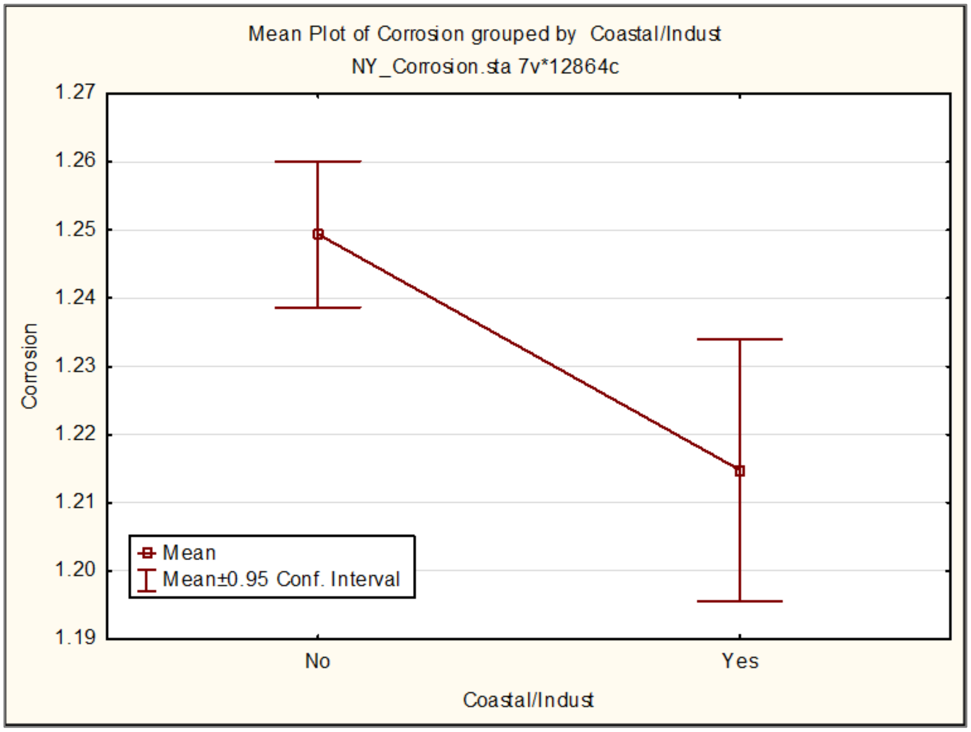


Figure 39. Mean Plot of Corrosion Severity vs. Coastal/Industrial or Urban/Rural Location

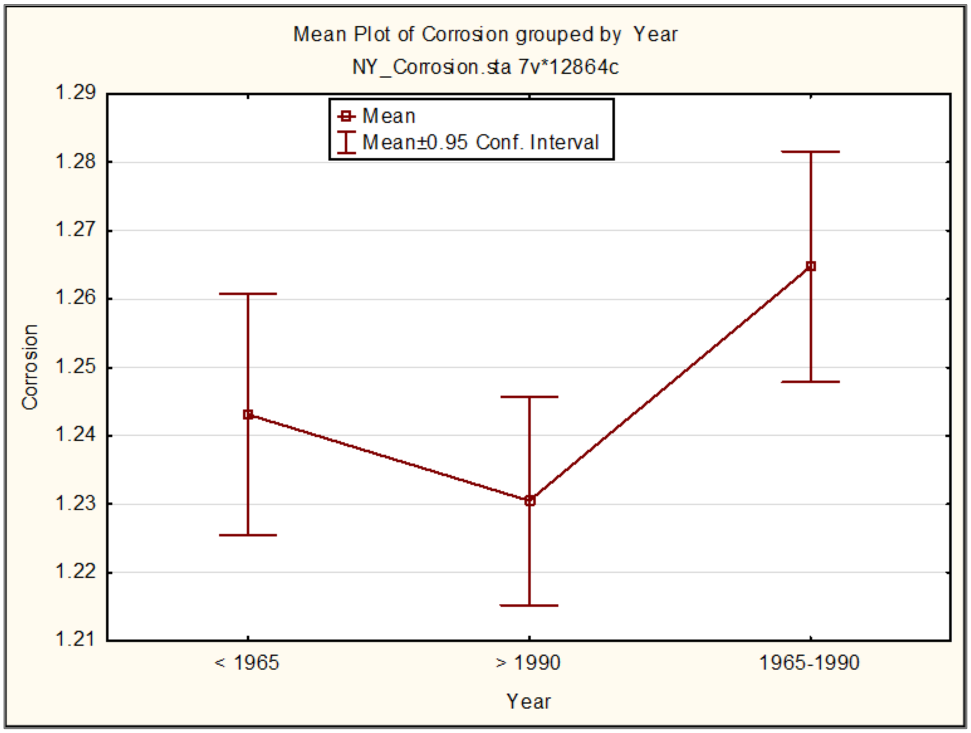


Figure 40. Mean Plot of Corrosion Severity vs. Installation Year

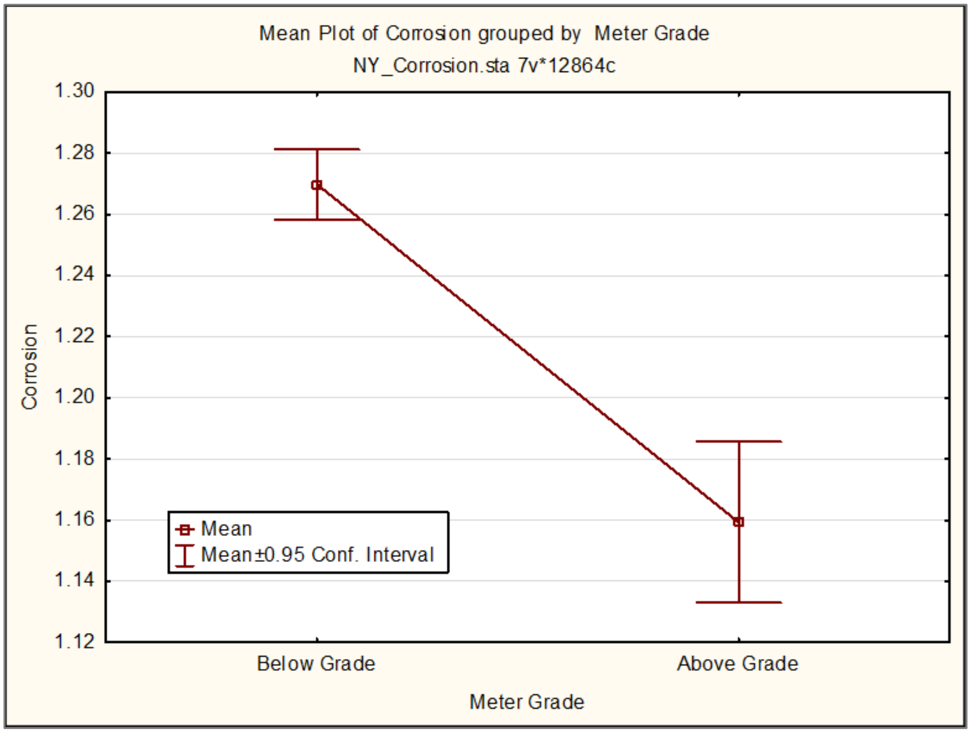


Figure 41. Mean Plot of Corrosion Severity vs. Meter Grade

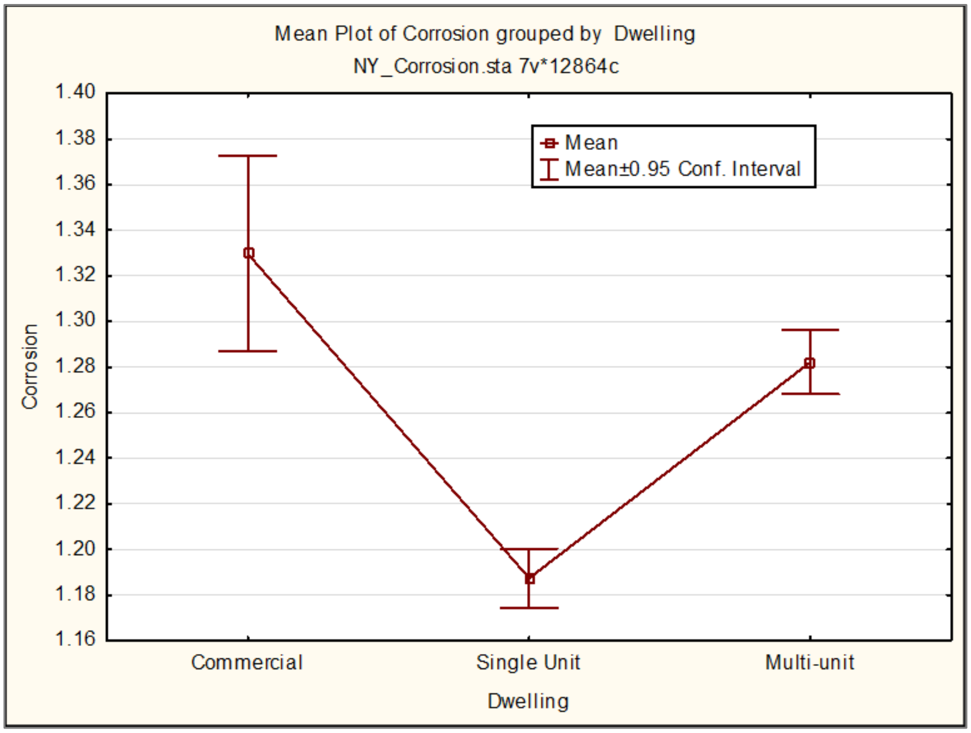


Figure 42. Mean Plot of Corrosion Severity vs. Dwelling Type

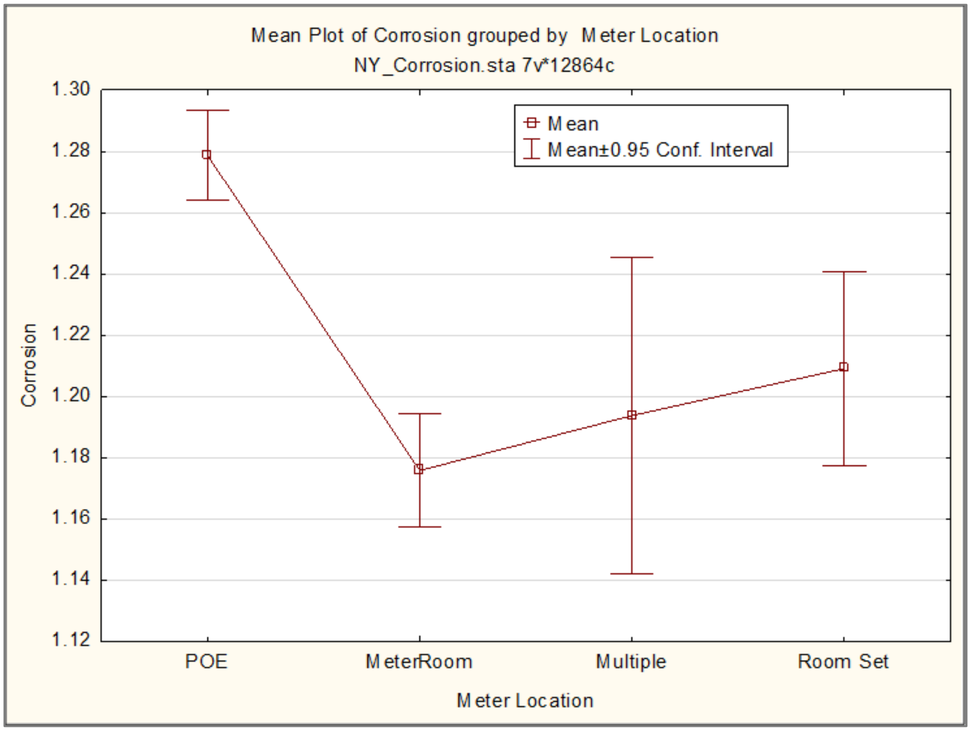


Figure 43. Mean Plot of Corrosion Severity vs. Meter Location (note POE means the Meter and Piping is Near the POE, not the POE section through the wall itself)

The findings of this section followed the historical and previously noted trends as detailed in Attachment 1 - White Paper Risk-Based Atmospheric Corrosion / Leak Survey Considerations with one exception. There was a higher corrosion index for Rural/Urban vs. Coastal/Industrial zones. It is felt that this might be able to explain by “human factors” since the coastal residences are typically very high-end homes and can be in better states of repair relative to the average residence. This is a hypothesis and would require further sampling and analysis to confirm. A similar trend was seen for leak indications in the next section, which helps support this hypothesis.

5.1.3 Corrosion Severity Sensitivity to Variables Summary

Based on the sensitivity checks discussed above, the variable categories that correlated to higher corrosion rates are noted in Table 8 below. Those categories that did not show statistical difference between their mean index levels and all the remaining categories for the variable were coded as not being statistically different with the other categories, and the variable category correlation as being neutral. The five "sensitive" variable categories for Corrosion that correlated to higher average corrosion index values are:

- Non-Conditioned Spaces
- Urban/Rural Geographic Locations
- Below Grade Asset Location
- Commercial/Multi-Unit Dwelling Type
- Meter and Piping Relative Location within the Building

Table 8. Corrosion Severity Analysis Summary Table

Random Sample Variable	Variable Categories	Statistical Ave. Difference Between Variable Categories?	Ave. Corrosion Index	Variable Category Correlation with Corrosion Severity
Conditioning	Conditioned	Yes	1.190	Lower
	Non-Conditioned		1.330	Higher
Rural/Urban or Coastal/Industrial	Rural or Urban	Yes	1.250	Higher
	Coastal or Industrial		1.215	Lower
Year of Installation	< 1965	No	1.245	Neutral
	1965-1990		1.255	
	> 1990		1.230	
Meter Grade	Below Grade	Yes	1.270	Higher
	Above Grade		1.160	Lower
Type of Dwelling	Commercial	No	1.330	Higher
	Multi-Unit		1.280	
	Single Unit	Yes	1.190	Lower
Meter Location	POE	Yes	1.280	Higher
	Meter Room	No	1.180	Lower
	Multiple Locations		1.195	
	Room Set		1.210	

5.1.4 ANOVA Regression Analysis Model for Corrosion Severity

To supplement the findings from the variable-by-variable analysis a factorial model, analysis of variance (ANOVA) was conducted and confirmed the findings in the previous section. Each parameter is significant, with the installation year being the least significant of the six prime variables. The ANOVA summary is presented in Table 9 below.

Table 9. ANOVA Factorial Model for Corrosion Severity vs. Prime Variables

Model or Variable Attribute	Sum of Squares	Degrees of Freedom	Mean Square	F Value	p-value (Prob > F)
Model	244.35	39	6.27	20.45	**< 0.0001**
A-Conditioned	36.34	1	36.34	123.54	**< 0.0001**
B-Coastal/ Industrial	4.62	1	4.62	15.71	**< 0.0001**
C-Installation Year	2.99	2	1.49	5.08	**0.0062**
D-Dwelling	53.46	2	26.73	90.86	**< 0.0001**
E-Meter Grade	15.36	1	15.36	52.22	**< 0.0001**
F-Meter Location	28.34	3	9.45	32.11	**< 0.0001**

- The Model F-value of 20.45 implies the model is significant. There is less than a 0.01% chance that an F-value this large could occur due to noise.
- p-values (Prob > F) less than 0.0500 (5%) indicate model terms are significant.
- p-values greater than 0.1000 indicate the model terms are not significant.

5.2 Leak Indication Sensitivity Analysis - Leak Indication vs. No Leak Indication as a Function of Variables

The leak indication sensitivity analysis is handled in a similar manner, but with one difference. Leak indications are a binary variable, meaning that either you (a) have a leak indication, or (b) do not have a leak indication. As explained earlier in the report, the threshold value for a leak indication is ≥ 0.1% Gas as measured by a CGI. Since we have only one variable we do not employ the use of variability plots as we did in the case of corrosion severity.

5.2.1 Analysis of Means for Leak Indications

In order to average the leak indication findings by variable we have assigned leak index values as follows:

1) Leak Indication < 0.1% Gas = 0
2) Leak Indication ≥ 0.1% Gas = 1

These average leak indication index plots for the same six primary variables shown in the corrosion severity sensitivity analysis are shown in Figure 44 to Figure 49..

As with the corrosion severity, the six primary variables for leak indications are:

- Space conditioning
- Geographic location
- Installation year
- Meter location to grade
- Dwelling type
- Meter location within the building

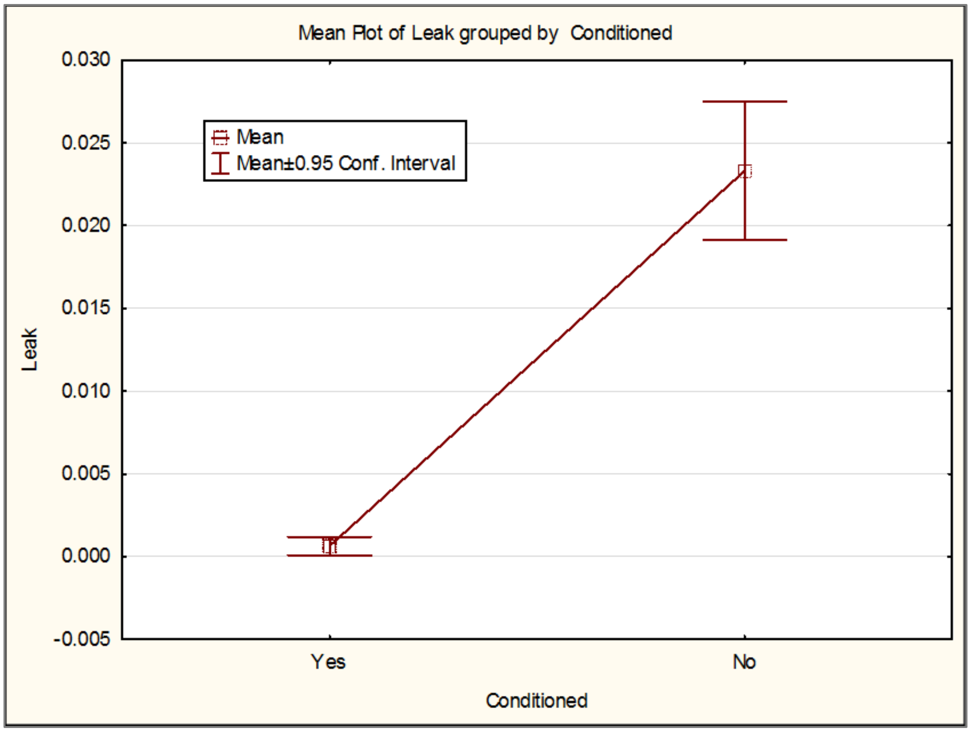


Figure 44. Mean Plot of Leak Indications. Space Conditioning

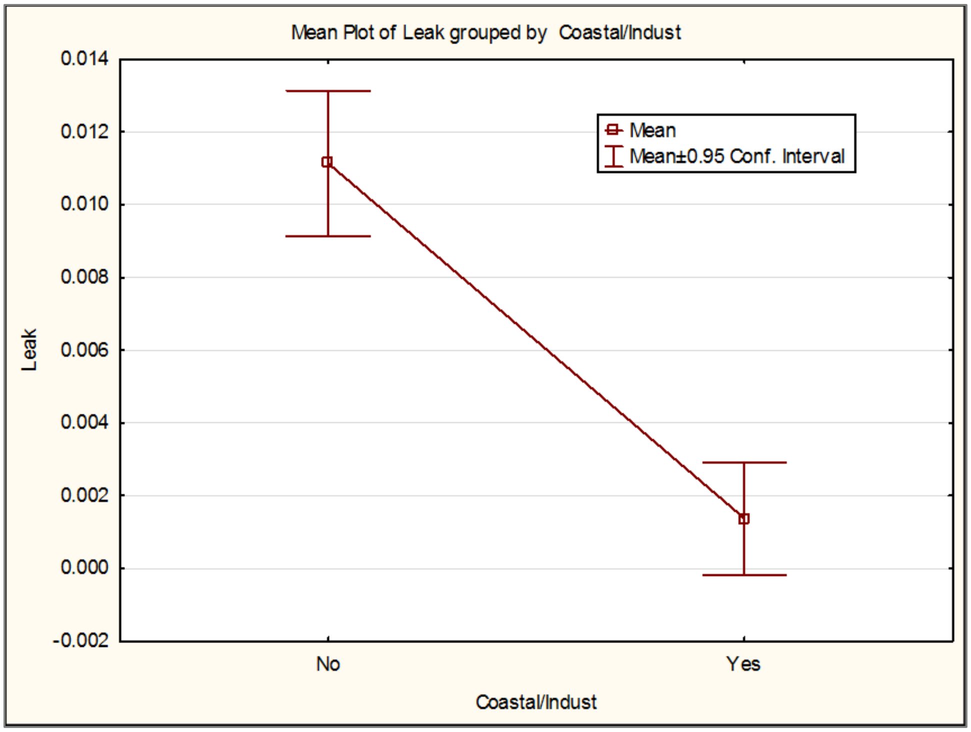


Figure 45. Mean Plot of Leak Indication vs. Coastal/Industrial or Urban/Rural Location

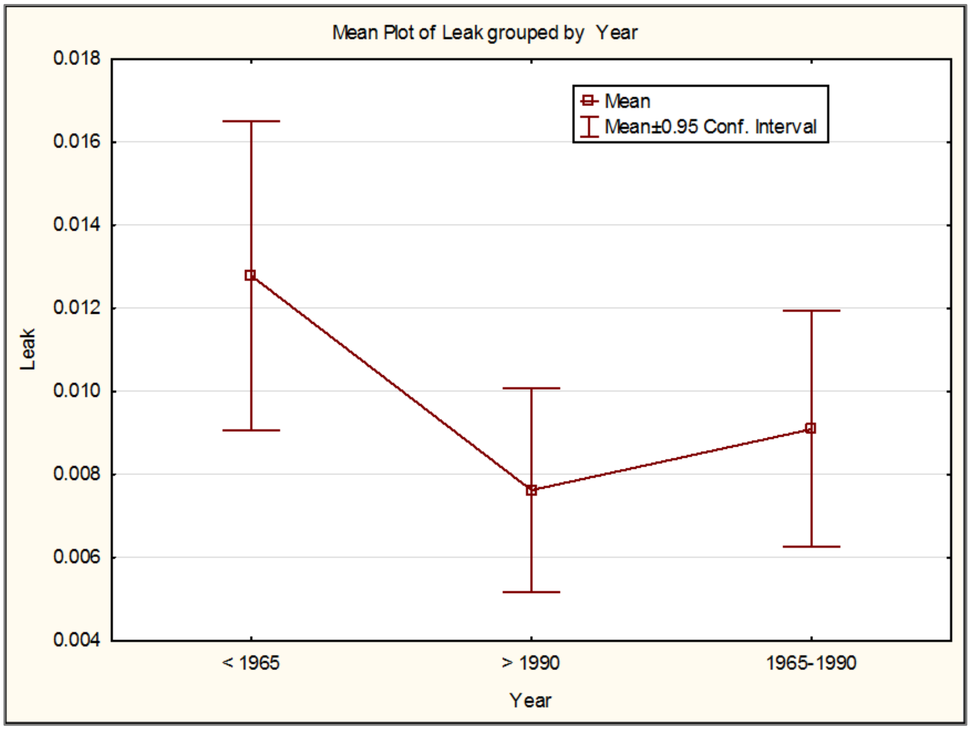


Figure 46. Mean Plot of Leak Indication vs. Installation Year

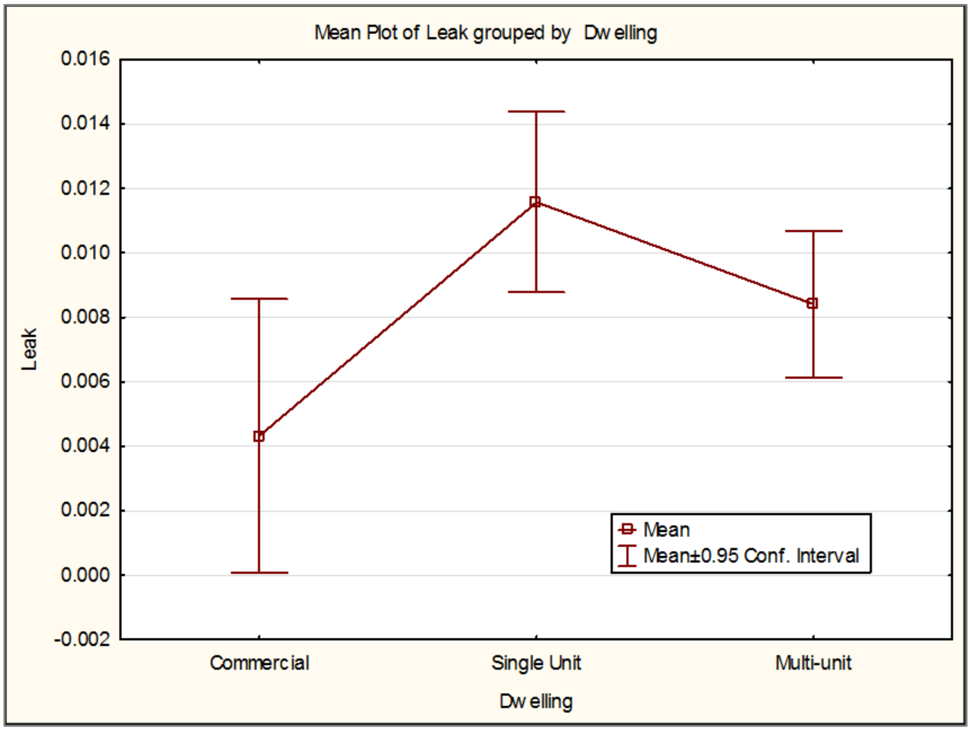


Figure 47. Mean Plot of Leak Indication vs. Dwelling Type

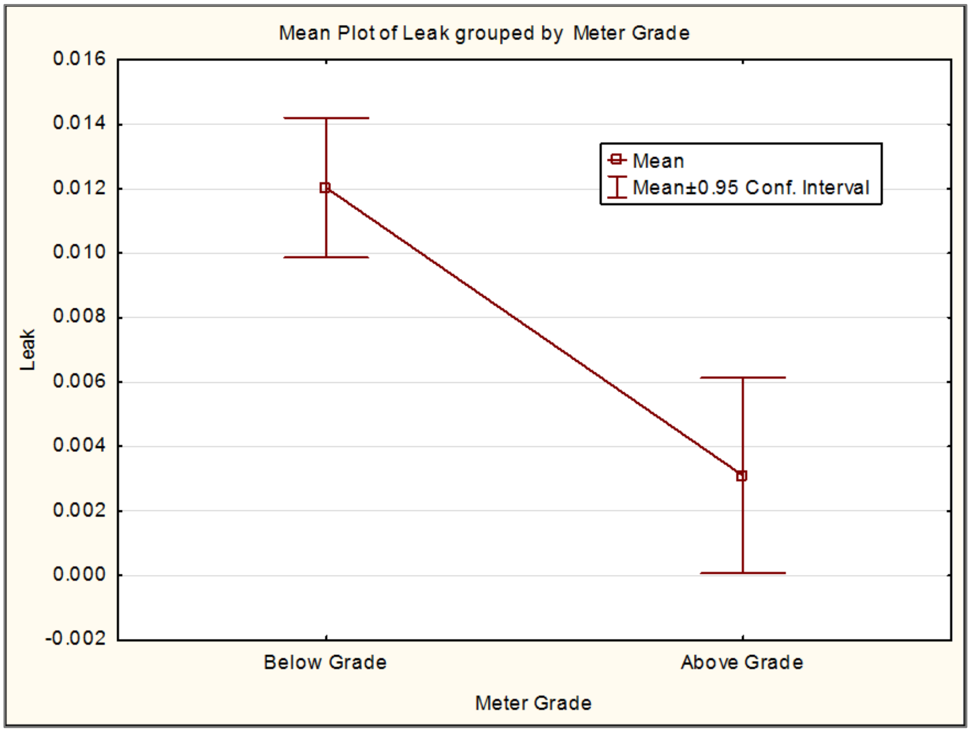


Figure 48. Mean Plot of Leak Indication vs. Meter Grade

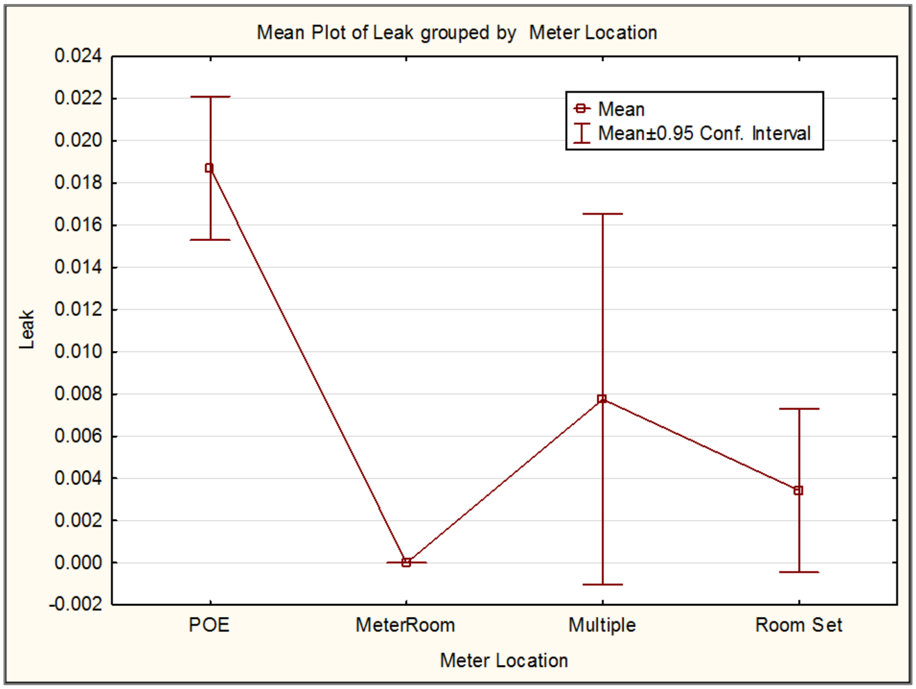


Figure 49. Mean Plot of Leak Indication vs. Meter Location (note POE means the Meter and Piping is Near the POE, not the POE section through the wall itself)

5.2.2 Leak Indication Sensitivity to Variables Summary

Based on the sensitivity checks discussed above, the variable categories that correlated to increased leak indications are noted in Table 10 below. Those categories that did not show statistical difference between their mean index levels and all the remaining categories for the variable were coded as not being statistically different with the other categories, and the variable category correlation as being neutral. The four "sensitive" variable categories for Corrosion that correlated to higher average leak index values are:

- Non-Conditioned Spaces
- Urban/Rural Geographic Locations
- Below Grade Asset Location
- Meter Location within the Building

Table 10. Leak Indication Analysis Summary Table

Random Sample Variable	Variable Categories	Statistical Ave. Difference Between Variable Categories?	Ave. Leak Index	Variable Category Correlation with Leak Occurance
Conditioning	Conditioned	Yes	0.001	Lower
	Non-Conditioned		0.023	Higher
Rural/Urban or Coastal/Industrial	Rural or Urban	Yes	0.011	Higher
	Coastal or Industrial		0.002	Lower
Year of Installation	< 1965	No	0.013	Neutral
	1965-1990		0.009	
	> 1990		0.008	
Meter Grade	Below Grade	Yes	0.012	Higher
	Above Grade		0.003	Lower
Type of Dwelling	Commercial	No	0.004	Neutral
	Multi-Unit		0.009	
	Single Unit		0.012	
Meter Location	POE	Yes	0.019	Higher
	Meter Room	No	0.000	Lower
	Multiple Locations		0.008	
	Room Set		0.004	

5.2.3 ANOVA Regression Analysis Model for Leak Indications

To supplement the findings from the variable-by-variable analysis a factorial model, analysis of variance (ANOVA) was conducted and reinforced the findings in the previous section. Each parameter is significant, except for installation year which was found to be not significant, i.e., the differences in leak index could be attributed to random variation. The ANOVA summary is presented in Table 11 below.

Table 11. ANOVA Factorial Model for Leak Indications vs. Prime Variables

Model or Variable Attribute	Sum of Squares	Degrees of Freedom	Mean Square	F Value	p-value (Prob > F)
Model	31.4	50	0.63	9.23	**< 0.0001**
A-Conditioned	*7.73*	*1*	*7.73*	*113.56*	***< 0.0001***
B-Coastal/ Industrial	*0.49*	*1*	*0.49*	*7.15*	***0.0075***
C-Installation Year	*0.047*	*2*	*0.023*	*0.34*	***0.7092***
D-Dwelling	*2.49*	*2*	*1.25*	*18.3*	***< 0.0001***
E-Meter Grade	*0.85*	*1*	*0.85*	*12.52*	***0.0004***
F-Meter Location	*3.46*	*3*	*1.15*	*16.96*	***< 0.0001***

- The Model F-value of 20.45 implies the model is significant. There is less than a 0.01% chance that an F-value this large could occur due to noise.
- p-values (Prob > F) less than **0.0500** (5%) indicate model terms are significant.
- p-values greater than **0.1000** indicate the model terms are not significant.

5.3 Combined Corrosion Severity and Leak Indication Analysis - Summary

The two responses were compared against each other and are plotted in Figure 50. This plot shows that locations that have leaks have a significantly higher corrosion index (21% higher) than those that do not.

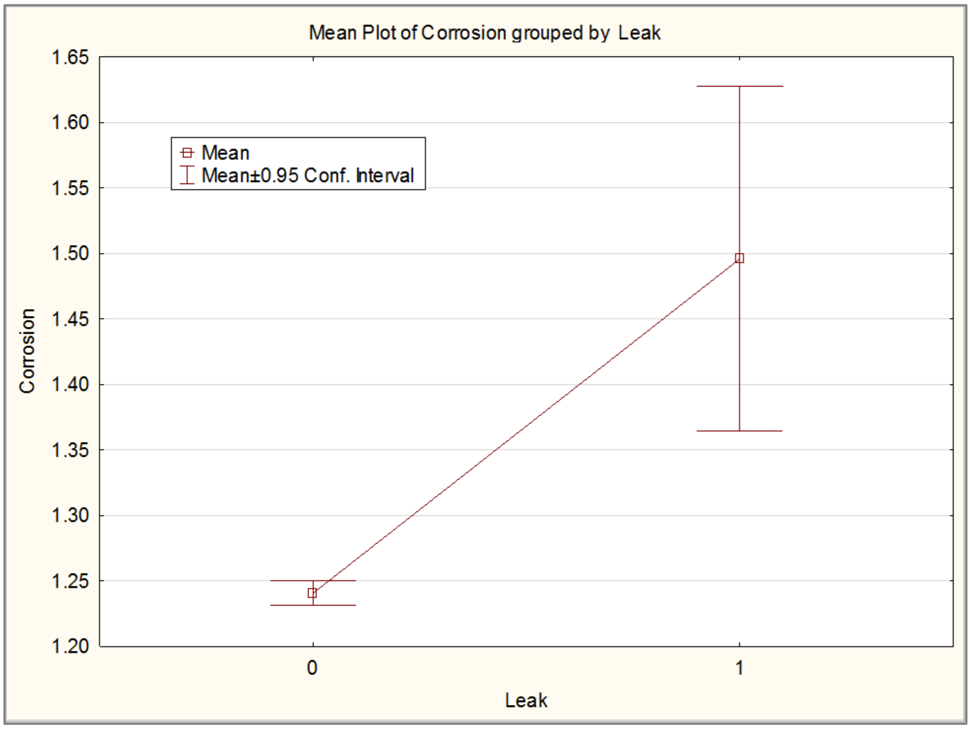


Figure 50. Mean Plot of Corrosion Severity Index vs. Leak Status

There is a strong correlation of high corrosion to increased leak Indications.

5.4 DIMP Assessment Matrix - Installation Attributes vs. Relative Risk Score

The results of the sensitivity analysis have been relatively ranked and prepared into a table that matches installation attributes (aka variable categories) for indoor meter and piping to a relative severity weight. The relative weights for each installation attribute variable can be added for an overall "likelihood" of severe corrosion/leak indication weighting. This overall likelihood severity weight can be multiplied with an operator-assigned consequence relative weighting to provide a relative risk weighting.

The risk weighting can then be categorized into an appropriate number of groups and used to assist with assignment of baseline and recurring inspection intervals with the higher risk groups having shorter intervals than the lower risk groups.

5.4.1 Relative Likelihood Weights (Law) for Installation Attributes

A relative weighting scale was developed based on the random sampling analysis that assigns a number from 1 to 15 (lower to higher likelihood risk) for each of the random sample variables that exhibited correlation to corrosion severity and leak indications. The relative likelihood weighting (Lw) assignments are shown in Table 12 below.

Table 12. Relative Likelihood Weighting for Random Sample Variables by Installation Attribute

Random Sample Variable	Installation Attributes	Relative Likelihood Weight (Lw)
Building POE Penetration vs. Interior Meter and Piping vs. Room Set	Building POE Penetration	15.0
	Interior Meter/Piping Near POE	10.0
	Unknown	10.0
	Interior Meter/Piping Meter Room	5.0
	Interior Meter/Piping Multiple Locations	5.0
	Room Set	1.0
Past Corrosion Levels High or Medium Severity	Yes	10.0
	Unknown	5.0
	No	1.0
Conditioning	Conditioned	1.0
	Unknown	5.0
	Non-Conditioned	10.0
Rural/Urban or Coastal/Industrial	Rural or Urban	5.0
	Coastal or Industrial	1.0
Meter Grade	Below Grade	10.0
	Unknown	5.0
	Above Grade	1.0

The weight ranges from 1 to 15 for the attributes as a function of the attributes correlation to increased corrosion severity or leak indications as follows:

Major	15
Moderate	10
Unknown	10
Minor	5
Neutral	1

This weighting range produces a maximum combined (added) weighting score for likelihood of corrosion/leak indication of 50 and a minimum of combined weighting score of 5.

The variables of year of installation and type of dwelling are not included in the weighting assignments since they exhibited no or very low correlation to likelihood of increased corrosion severity or leak indication from the sensitivity analysis. Examples of three installation sites that range the minimum, maximum, and midrange combined attribute weightings are shown in Table 13 below.

Table 13. Relative Likelihood Weightings for Random Sample Variables by Installation Attribute

	Installation Attribute Examples					
Variable	**Site A. Midrange**		**Site B. Min**		**Site C. Max**	
Building POE Penetration vs. Interior Meter and Piping vs. Room Set	POE Penetration		POE Penetration		POE Penetration	15
	Interior Meter/Piping Near POE	10	Interior Meter/Piping Near POE		Interior Meter/Piping Near POE	
	Unknown		Unknown		Unknown	
	Interior Meter/Piping Meter Room		Interior Meter/Piping Meter Room		Interior Meter/Piping Meter Room	
	Interior Meter/Piping Multiple Locations		Interior Meter/Piping Multiple Locations		Interior Meter/Piping Multiple Locations	
	Room Set		Room Set	1	Room Set	
Past Corrosion Levels High or Medium Severity	Yes		Yes		Yes	10
	Unknown	5	Unknown		Unknown	
	No		No	1	No	
Conditioning	Conditioned	1	Conditioned	1	Conditioned	
	Unknown		Unknown		Unknown	
	Non-Conditioned		Non-Conditioned		Non-Conditioned	10
Rural/Urban or Coastal/Industrial	Rural or Urban	5	Rural or Urban		Rural or Urban	5
	Coastal or Industrial		Coastal or Industrial	1	Coastal or Industrial	
Meter Grade	Below Grade	10	Below Grade		Below Grade	10
	Unknown		Unknown		Unknown	
	Above Grade		Above Grade	1	Above Grade	
Lw TOTALS		**31**		**5**		**50**

5.4.2 Relative Consequence Weights (Cw) for Installation Attributes

As with the likelihood weighting (Lw), one can develop a set of consequence weights (Cw) based on installation attributes.

Since consequence implies a loss of some kind, the loss or damage must be pre-determined. *Consequences* that are commonly measured in a risk assessment[2] include:

- Fatalities
- Injuries
- Property Loss
- Environmental Harm
- Monetary Loss, Including Service Interruption Costs
- Operator Judges it a Significant Consequence

The *receptors* of the consequence of a gas leak or explosion could include[3]:

- Population Density
- Permanent Population
- Transitory/Occasional Population
- Special (Restricted Mobility) Population
- Collateral Safety
- Structural Value
- High-Value Areas
- Contents of and Area
- Environmental Sensitivities
- Business Impacts
- Property Damage

The development of a consequence weighting is best left to each operator or common group of operators that knows their system and its details. The relative Cw weights should be based on the perceived vulnerability and consequence potential of each receptor.

To facilitate the discussion of combining likelihood and consequence, a very simple (exemplary) and incomplete set of relative consequence weightings could be considered as shown in Table 14. This only takes into account the overall population density as defined by DOT Class Location with a Business District added in as well.

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[2] Muhlbauer, W.K., Pipeline Risk Assessment - The definitive approach and its role in risk management, Expert Publishing, Austin, TX, 2015.

[3] Muhlbauer, W.K., Pipeline Risk Management Manual, Elsevier, New York, 2004.

Table 14. Exemplary (Incomplete) Relative Consequence Weightings for Random Sample Variables by Installation Attribute

Population Installation Attribute	Relative Consequence Weighting (Cw)
DOT Class 1 or 2 Location	1
DOT Class 3 Location	5
DOT Class 4 Location	10
Business District	15

5.4.3 Relative Risk Weights (Rw) for Installation Attributes

In its simplest form, relative risk can be defined as likelihood x consequence.

For a set of relative risk weights this can be defined per equation 1:

$$Rw = Lw \times Cw \qquad \text{(equation 1)}$$

If we use the three examples from the likelihood weightings section and assign them a consequence weighting we can see how a relative risk score could be calculated, see Table 15.

Table 15. Example of Relative Risk Weightings (Rw) by Installation Attribute

Site	Combined Relative Likelihood Weighting (Lw) for Site	Relative Consequence Weighting (Cw) for Site	Relative Risk Weighting (Rw) for Site
A	31	15 (Bus. District)	465
B	5	10 (CL 4)	50
C	50	1 (CL 1)	50

As shown above, even though site A had a lower Lw than site C, its Rw was higher due to the contribution of the higher Cw.

As noted at the beginning of this section, the risk weighting can then be categorized into an appropriate number of groups and used to assist with assignment of baseline and recurring inspection intervals with the higher risk groups having shorter intervals than the lower risk groups.

6 Inference of Sample Results to the Operator and Statewide Population of Assets - Conditional Probability Analysis

6.1 Corrosion and Leak Indication Roll Up Estimates

Conditional probability analysis was used to calculate the probable corrosion severity and leak indication levels for each category of assets in the entire *population*, including lower and upper confidence levels that reflect the uncertainty in the predictions.

This type of analysis can provide the input for DIMP considerations since it provides the likelihood of corrosion severity and leak indication levels in the population that the sample was drawn from. The confidence intervals allow for the proper consideration of risk since sub-populations that had smaller numbers of random samples drawn from them will have inherently larger confidence bands around the most likely value. This leads to a conservative adjustment by selection of a confidence level and using the upper confidence limit for undesirable proportions, e.g., severe corrosion or leaks ≥ 0.1% Gas.

The population predictions for the NY operator combined are presented in Table 16. These are broken out into two categories for the population in NY: (a) indoor and POE assets combined, and (b) room sets by themselves. The most likely values are listed for each corrosion severity and leaks, along with the 95% single sided lower and upper confidence limits.

For example, for all indoor and POE assets (combined) we would expect there to be 0.5% of the population in the high corrosion severity with no more than 0.6% with a 95% confidence.

For leaks there are two columns, one for Leaks ≥ 0.1% Gas (50x safety margin to methane LEL) and one for Leaks ≥ 5% Gas (methane LEL). One can see that there is a less than 1 in 10,000 expected occurrence of leaks ≥ 5% Gas. We did not include this analysis for room sets since no leaks in this range were observed in the sample set.

Table 16. Population Predictions for Corrosion Severity and Leak Levels - NY Roll Up

Estimated Corrosion Severity and Leak Percentages of Asset Populations - Predicted Values with 95% Upper and Lower Limits			Corrosion Severity Categories				Leak Categories	
			None/Minimal Corrosion	Low Corrosion	Medium Corrosion	High Corrosion	Leaks ≥ 0.1% Gas	Leaks ≥ 5% Gas
Category	NY Indoor + POE	95% UL	81.2%	15.1%	4.6%	0.6%	1.11%	0.0376%
		Most Likely Value	**80.7%**	**14.5%**	**4.3%**	**0.5%**	**0.95%**	**0.0079%**
		95% LL	80.1%	14.0%	4.0%	0.4%	0.82%	0.0028%
	NY Room Sets	95% UL	84.6%	17.6%	2.8%	0.8%	1.43%	None
		Most Likely Value	**82.5%**	**15.4%**	**1.8%**	**0.2%**	**0.73%**	
		95% LL	80.2%	13.5%	1.2%	0.1%	0.40%	

The data presented in Table 16 is also shown graphically in Figure 51 to Figure 56 below. The error bars are the 95% single sided lower and upper confidence limits and the plotted point is the most likely value for the proportion of the plotted item in the NY asset population.

6.1.1 Corrosion Severity

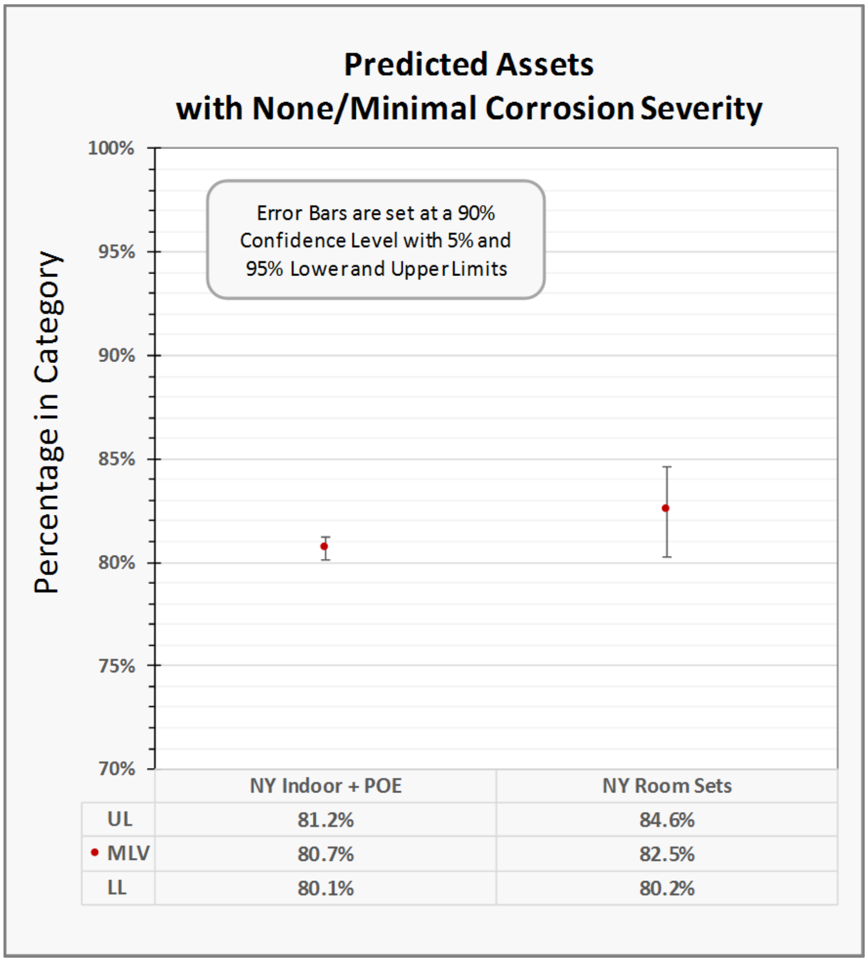
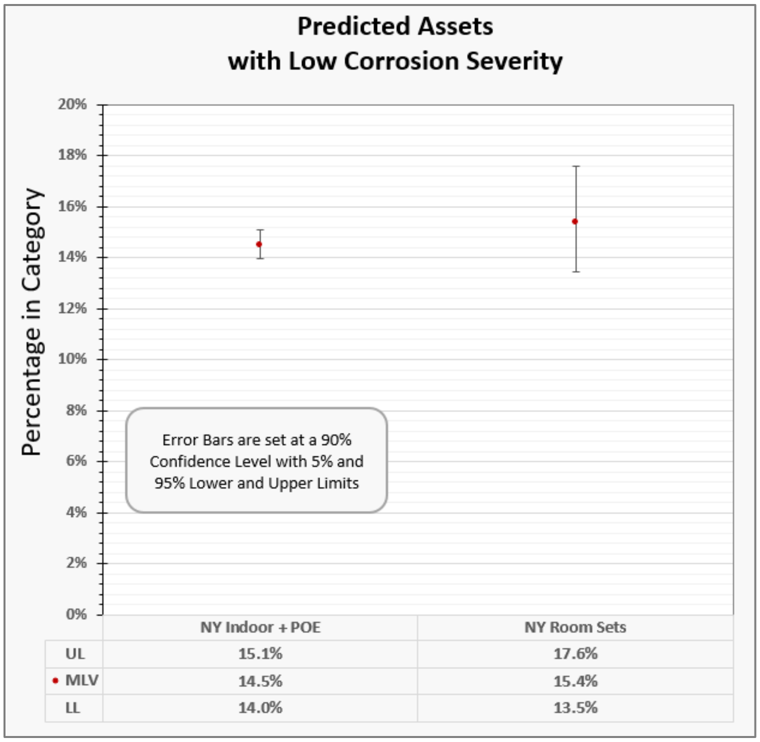


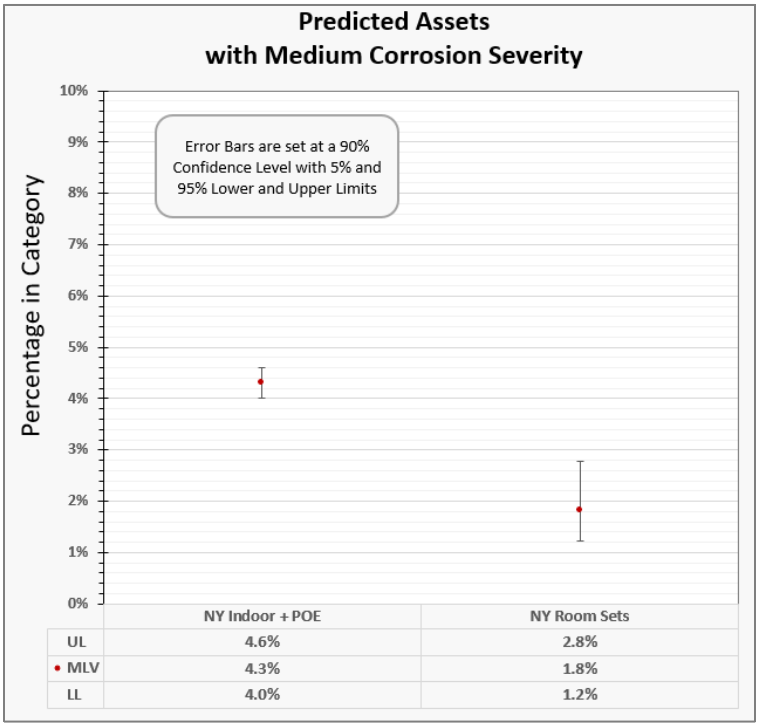
Figure 51. Predicted Percent of Indoor + POE and Room Set Assets Exhibiting a None/Minimal Corrosion Severity



Error Bars are set at a 90% Confidence Level with 5% and 95% Lower and Upper Limits

	NY Indoor + POE	NY Room Sets
UL	15.1%	17.6%
• MLV	14.5%	15.4%
LL	14.0%	13.5%

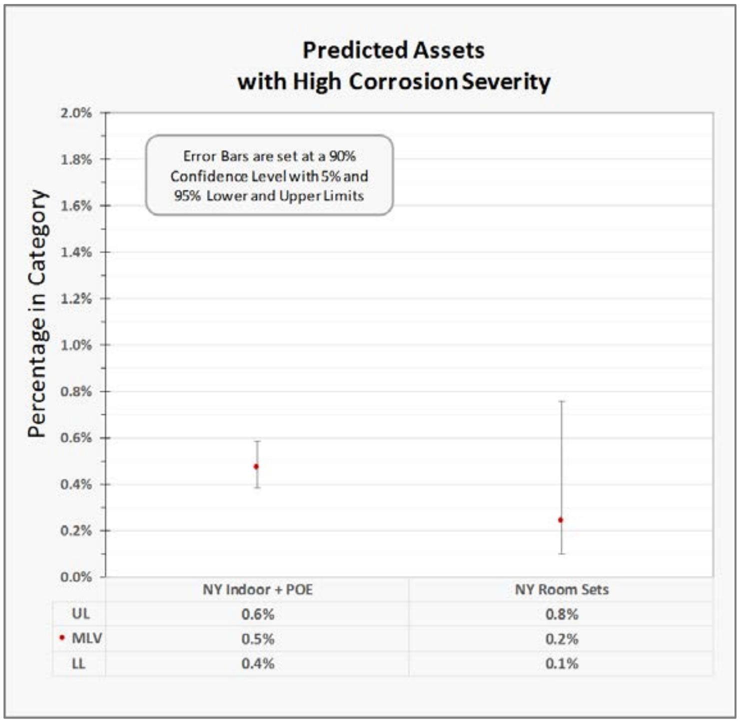
Figure 52. Predicted Percent of Indoor + POE and Room Set Assets Exhibiting a Low Corrosion Severity



Error Bars are set at a 90% Confidence Level with 5% and 95% Lower and Upper Limits

	NY Indoor + POE	NY Room Sets
UL	4.6%	2.8%
• MLV	4.3%	1.8%
LL	4.0%	1.2%

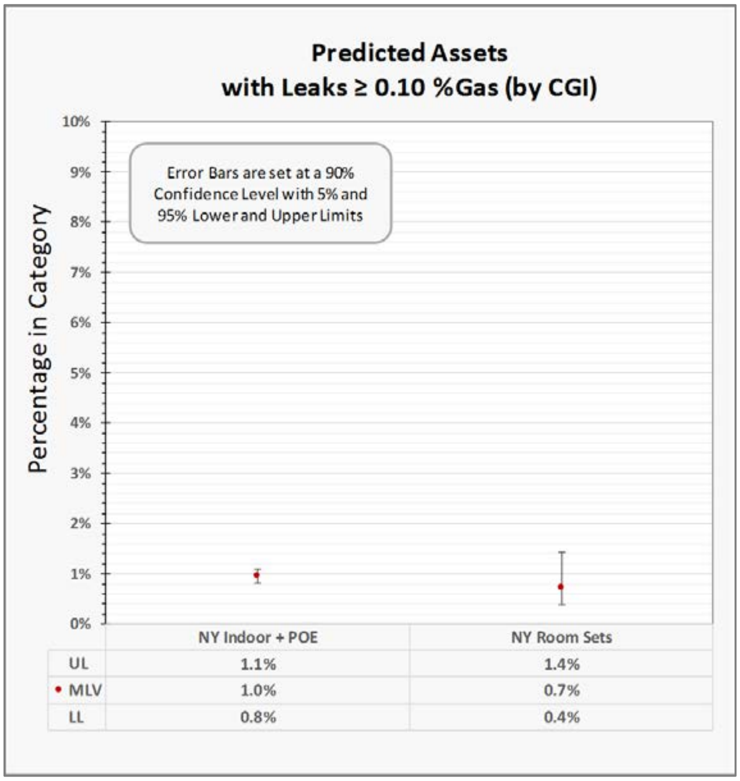
Figure 53. Predicted Percent of Indoor + POE and Room Set Assets Exhibiting a Medium Corrosion Severity



	NY Indoor + POE	NY Room Sets
UL	0.6%	0.8%
• MLV	0.5%	0.2%
LL	0.4%	0.1%

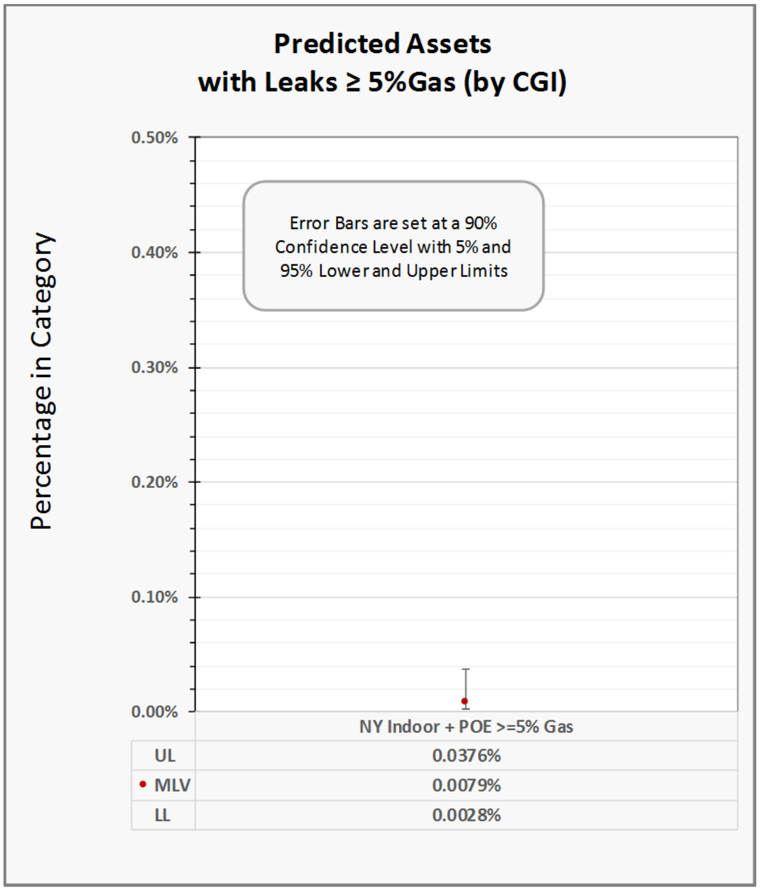
Figure 54. Predicted Percent of Indoor + POE and Room Set Assets Exhibiting a High Corrosion Severity

6.1.2 Gas Leak Indications



	NY Indoor + POE	NY Room Sets
UL	1.1%	1.4%
• MLV	1.0%	0.7%
LL	0.8%	0.4%

Figure 55. Predicted Percent of Indoor + POE and Room Set Assets Exhibiting a Leak Indication ≥ 0.1% Gas



Error Bars are set at a 90% Confidence Level with 5% and 95% Lower and Upper Limits

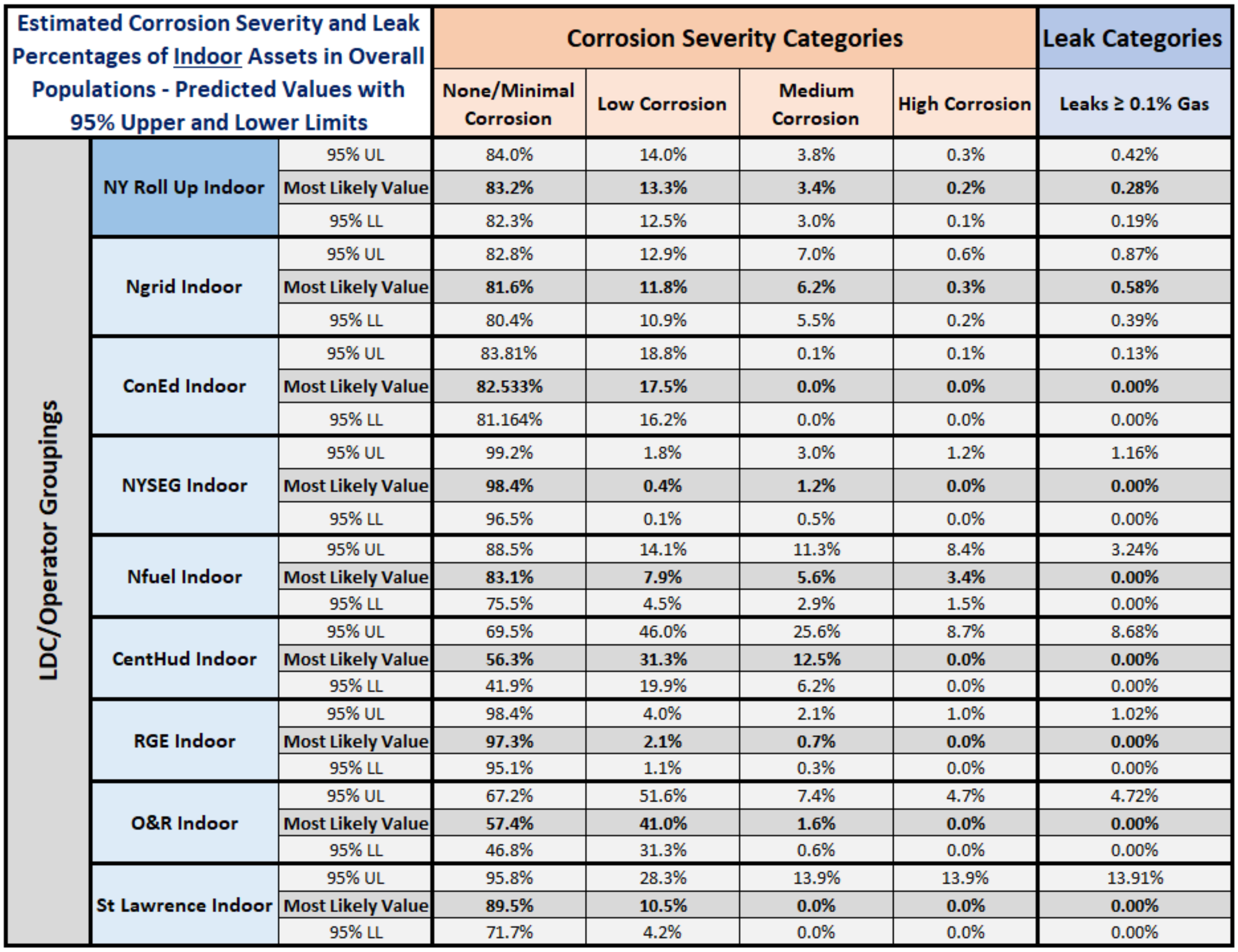
	NY Indoor + POE >=5% Gas
UL	0.0376%
● MLV	0.0079%
LL	0.0028%

Figure 56. Predicted Percent of Indoor + POE Assets Exhibiting a Leak Indication ≥ 5% Gas

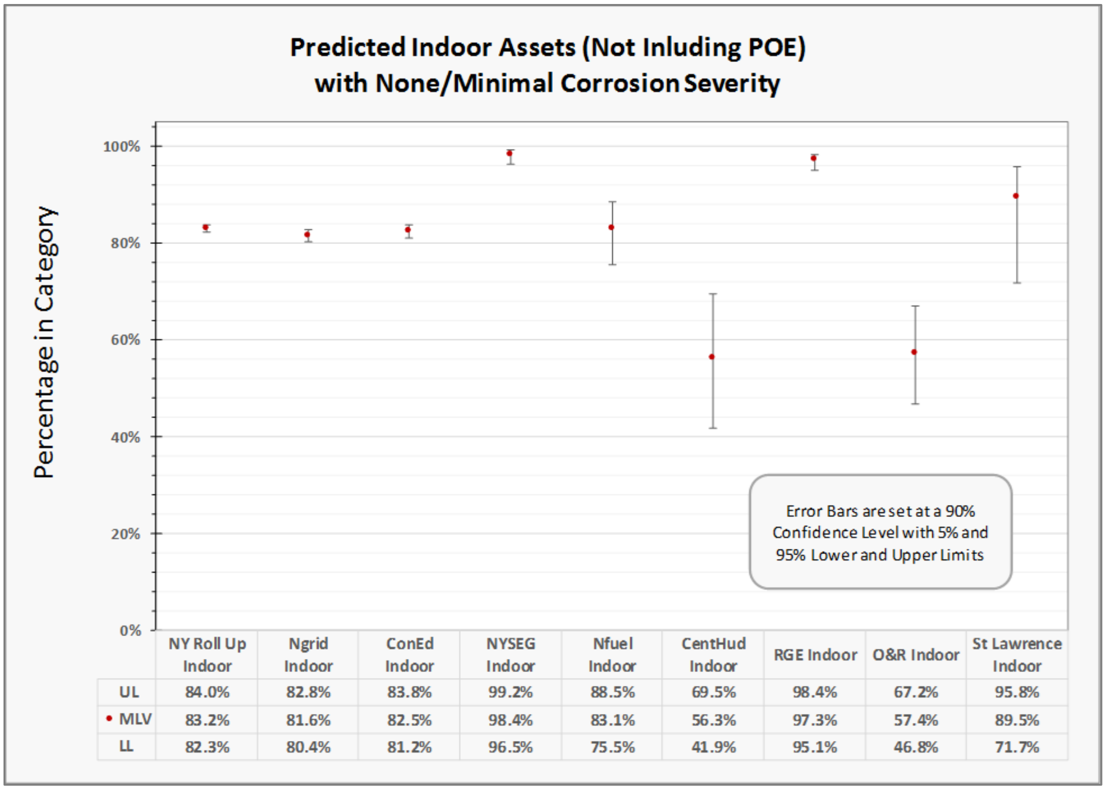
6.2 Indoor (Not Including POE) Assets - By NY Operators

The same type of probabilistic analysis was completed for indoor assets only (not including POE) by NY operator, along with a NY operator combined roll-up. The predictions for the NY asset indoor population are shown in Table 17 and graphically in Figure 57 to Figure 61.

Table 17. Population Predictions for Indoor Asset Corrosion Severity and Leak Levels - By Operator



Estimated Corrosion Severity and Leak Percentages of Indoor Assets in Overall Populations - Predicted Values with 95% Upper and Lower Limits			Corrosion Severity Categories				Leak Categories
			None/Minimal Corrosion	Low Corrosion	Medium Corrosion	High Corrosion	Leaks ≥ 0.1% Gas
LDC/Operator Groupings	NY Roll Up Indoor	95% UL	84.0%	14.0%	3.8%	0.3%	0.42%
		Most Likely Value	**83.2%**	**13.3%**	**3.4%**	**0.2%**	**0.28%**
		95% LL	82.3%	12.5%	3.0%	0.1%	0.19%
	Ngrid Indoor	95% UL	82.8%	12.9%	7.0%	0.6%	0.87%
		Most Likely Value	**81.6%**	**11.8%**	**6.2%**	**0.3%**	**0.58%**
		95% LL	80.4%	10.9%	5.5%	0.2%	0.39%
	ConEd Indoor	95% UL	83.81%	18.8%	0.1%	0.1%	0.13%
		Most Likely Value	**82.533%**	**17.5%**	**0.0%**	**0.0%**	**0.00%**
		95% LL	81.164%	16.2%	0.0%	0.0%	0.00%
	NYSEG Indoor	95% UL	99.2%	1.8%	3.0%	1.2%	1.16%
		Most Likely Value	**98.4%**	**0.4%**	**1.2%**	**0.0%**	**0.00%**
		95% LL	96.5%	0.1%	0.5%	0.0%	0.00%
	Nfuel Indoor	95% UL	88.5%	14.1%	11.3%	8.4%	3.24%
		Most Likely Value	**83.1%**	**7.9%**	**5.6%**	**3.4%**	**0.00%**
		95% LL	75.5%	4.5%	2.9%	1.5%	0.00%
	CentHud Indoor	95% UL	69.5%	46.0%	25.6%	8.7%	8.68%
		Most Likely Value	**56.3%**	**31.3%**	**12.5%**	**0.0%**	**0.00%**
		95% LL	41.9%	19.9%	6.2%	0.0%	0.00%
	RGE Indoor	95% UL	98.4%	4.0%	2.1%	1.0%	1.02%
		Most Likely Value	**97.3%**	**2.1%**	**0.7%**	**0.0%**	**0.00%**
		95% LL	95.1%	1.1%	0.3%	0.0%	0.00%
	O&R Indoor	95% UL	67.2%	51.6%	7.4%	4.7%	4.72%
		Most Likely Value	**57.4%**	**41.0%**	**1.6%**	**0.0%**	**0.00%**
		95% LL	46.8%	31.3%	0.6%	0.0%	0.00%
	St Lawrence Indoor	95% UL	95.8%	28.3%	13.9%	13.9%	13.91%
		Most Likely Value	**89.5%**	**10.5%**	**0.0%**	**0.0%**	**0.00%**
		95% LL	71.7%	4.2%	0.0%	0.0%	0.00%

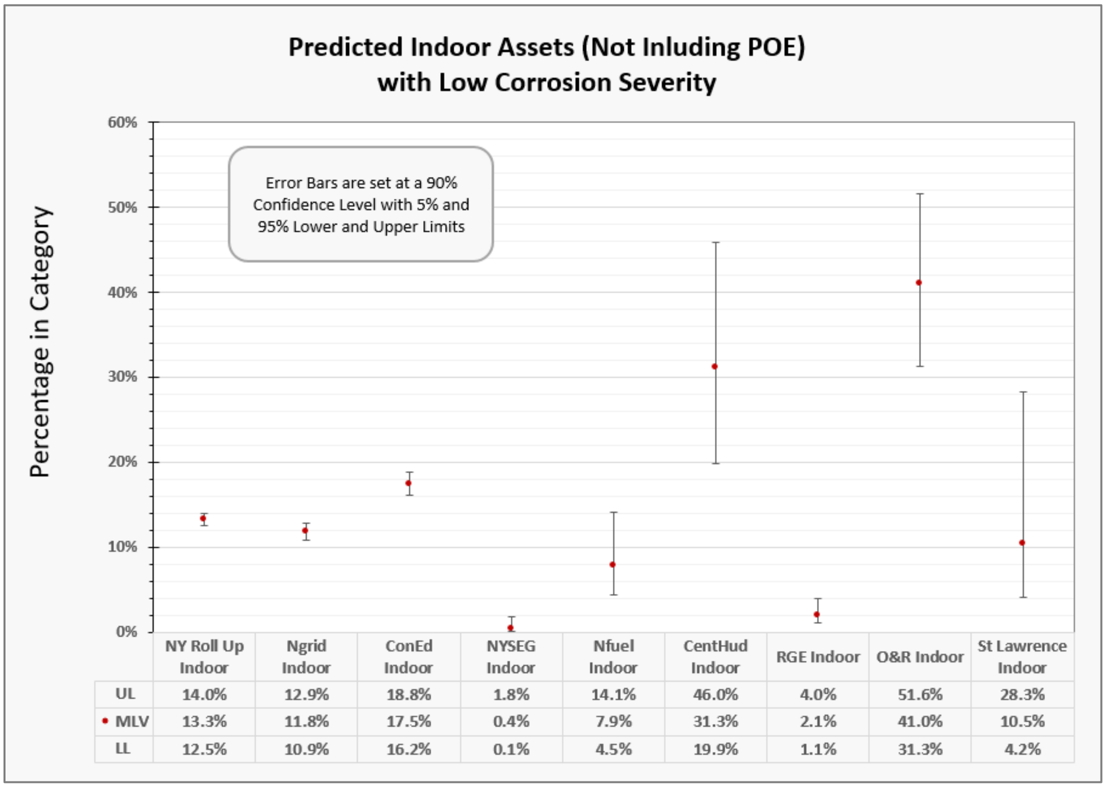


Predicted Indoor Assets (Not Inluding POE) with None/Minimal Corrosion Severity

Error Bars are set at a 90% Confidence Level with 5% and 95% Lower and Upper Limits

	NY Roll Up Indoor	Ngrid Indoor	ConEd Indoor	NYSEG Indoor	Nfuel Indoor	CentHud Indoor	RGE Indoor	O&R Indoor	St Lawrence Indoor
UL	84.0%	82.8%	83.8%	99.2%	88.5%	69.5%	98.4%	67.2%	95.8%
• MLV	83.2%	81.6%	82.5%	98.4%	83.1%	56.3%	97.3%	57.4%	89.5%
LL	82.3%	80.4%	81.2%	96.5%	75.5%	41.9%	95.1%	46.8%	71.7%

Figure 57. Predicted Percent of Indoor Assets Exhibiting a None/Minimal Corrosion Severity by Operator

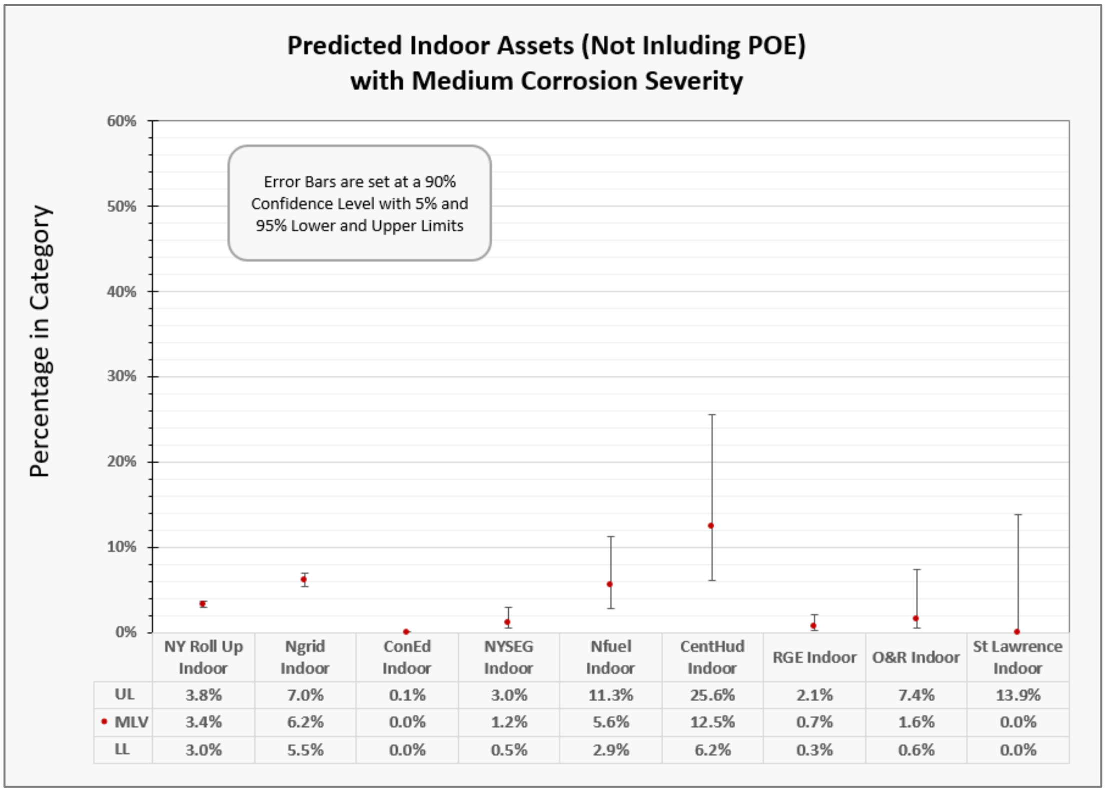


Predicted Indoor Assets (Not Inluding POE) with Low Corrosion Severity

Error Bars are set at a 90% Confidence Level with 5% and 95% Lower and Upper Limits

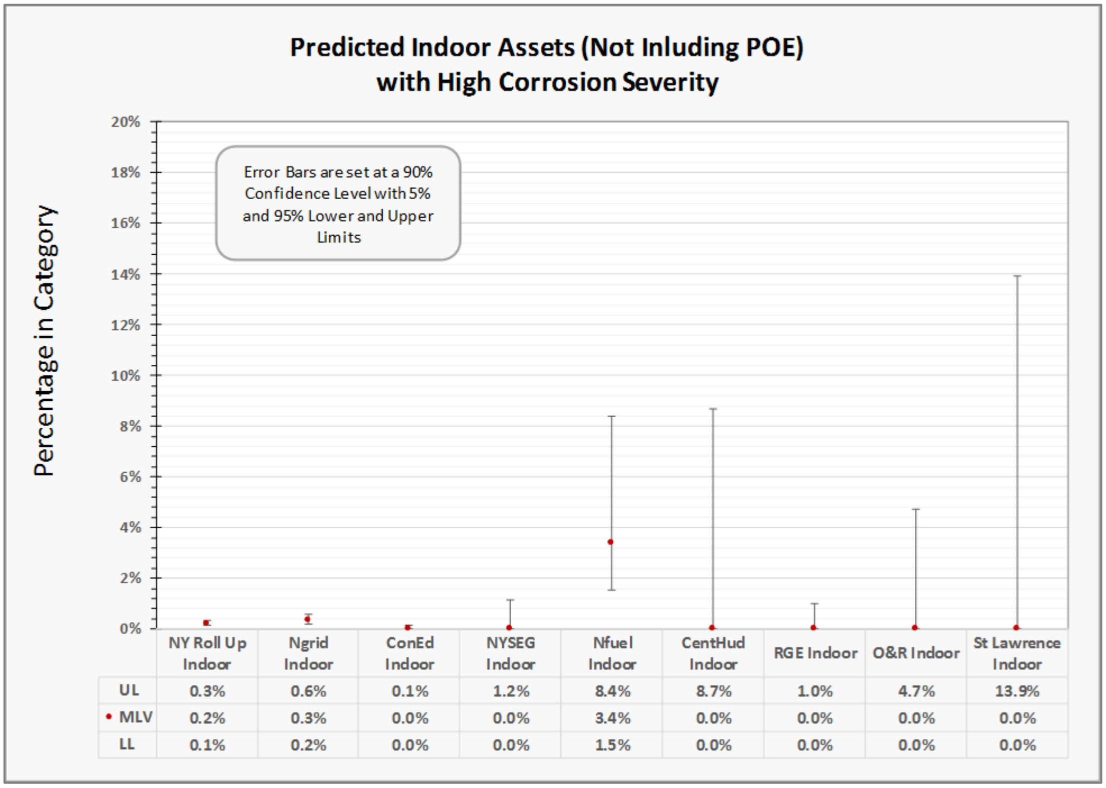
	NY Roll Up Indoor	Ngrid Indoor	ConEd Indoor	NYSEG Indoor	Nfuel Indoor	CentHud Indoor	RGE Indoor	O&R Indoor	St Lawrence Indoor
UL	14.0%	12.9%	18.8%	1.8%	14.1%	46.0%	4.0%	51.6%	28.3%
• MLV	13.3%	11.8%	17.5%	0.4%	7.9%	31.3%	2.1%	41.0%	10.5%
LL	12.5%	10.9%	16.2%	0.1%	4.5%	19.9%	1.1%	31.3%	4.2%

Figure 58. Predicted Percent of Indoor Assets Exhibiting a Low Corrosion Severity by Operator



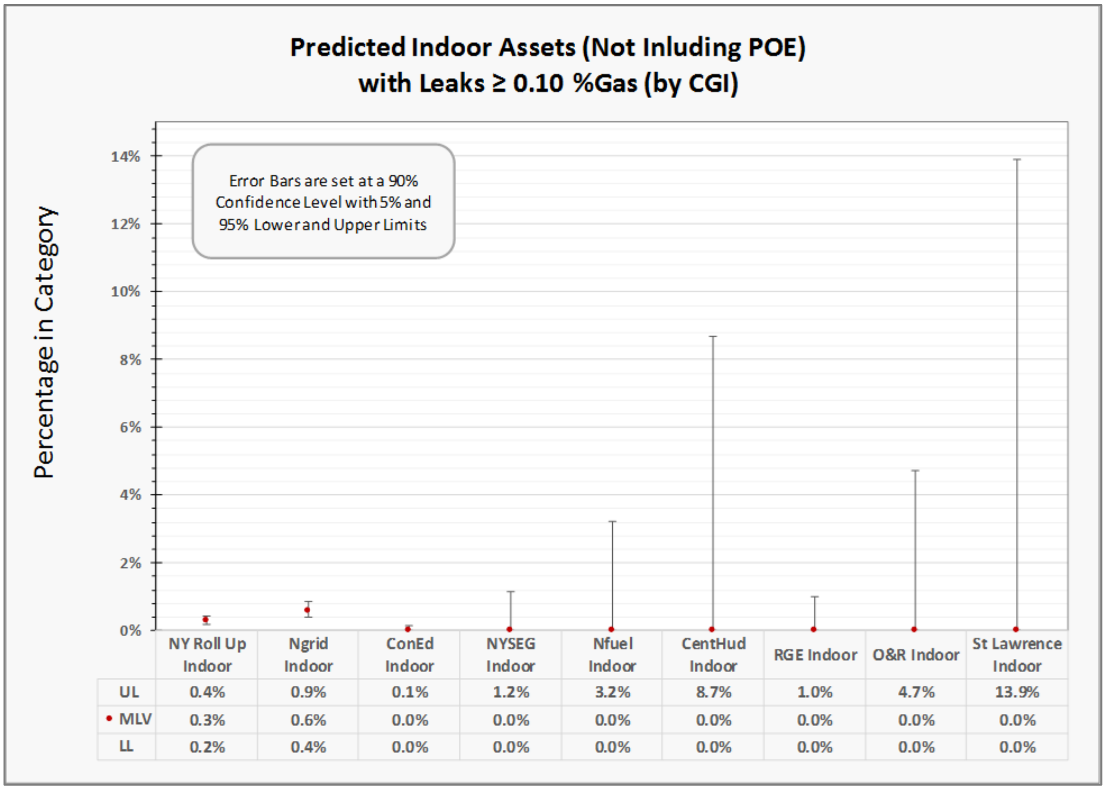
	NY Roll Up Indoor	Ngrid Indoor	ConEd Indoor	NYSEG Indoor	Nfuel Indoor	CentHud Indoor	RGE Indoor	O&R Indoor	St Lawrence Indoor
UL	3.8%	7.0%	0.1%	3.0%	11.3%	25.6%	2.1%	7.4%	13.9%
• MLV	3.4%	6.2%	0.0%	1.2%	5.6%	12.5%	0.7%	1.6%	0.0%
LL	3.0%	5.5%	0.0%	0.5%	2.9%	6.2%	0.3%	0.6%	0.0%

Figure 59. Predicted Percent of Indoor Assets Exhibiting a Medium Corrosion Severity by Operator



	NY Roll Up Indoor	Ngrid Indoor	ConEd Indoor	NYSEG Indoor	Nfuel Indoor	CentHud Indoor	RGE Indoor	O&R Indoor	St Lawrence Indoor
UL	0.3%	0.6%	0.1%	1.2%	8.4%	8.7%	1.0%	4.7%	13.9%
• MLV	0.2%	0.3%	0.0%	0.0%	3.4%	0.0%	0.0%	0.0%	0.0%
LL	0.1%	0.2%	0.0%	0.0%	1.5%	0.0%	0.0%	0.0%	0.0%

Figure 60. Predicted Percent of Indoor Assets Exhibiting a High Corrosion Severity by Operator



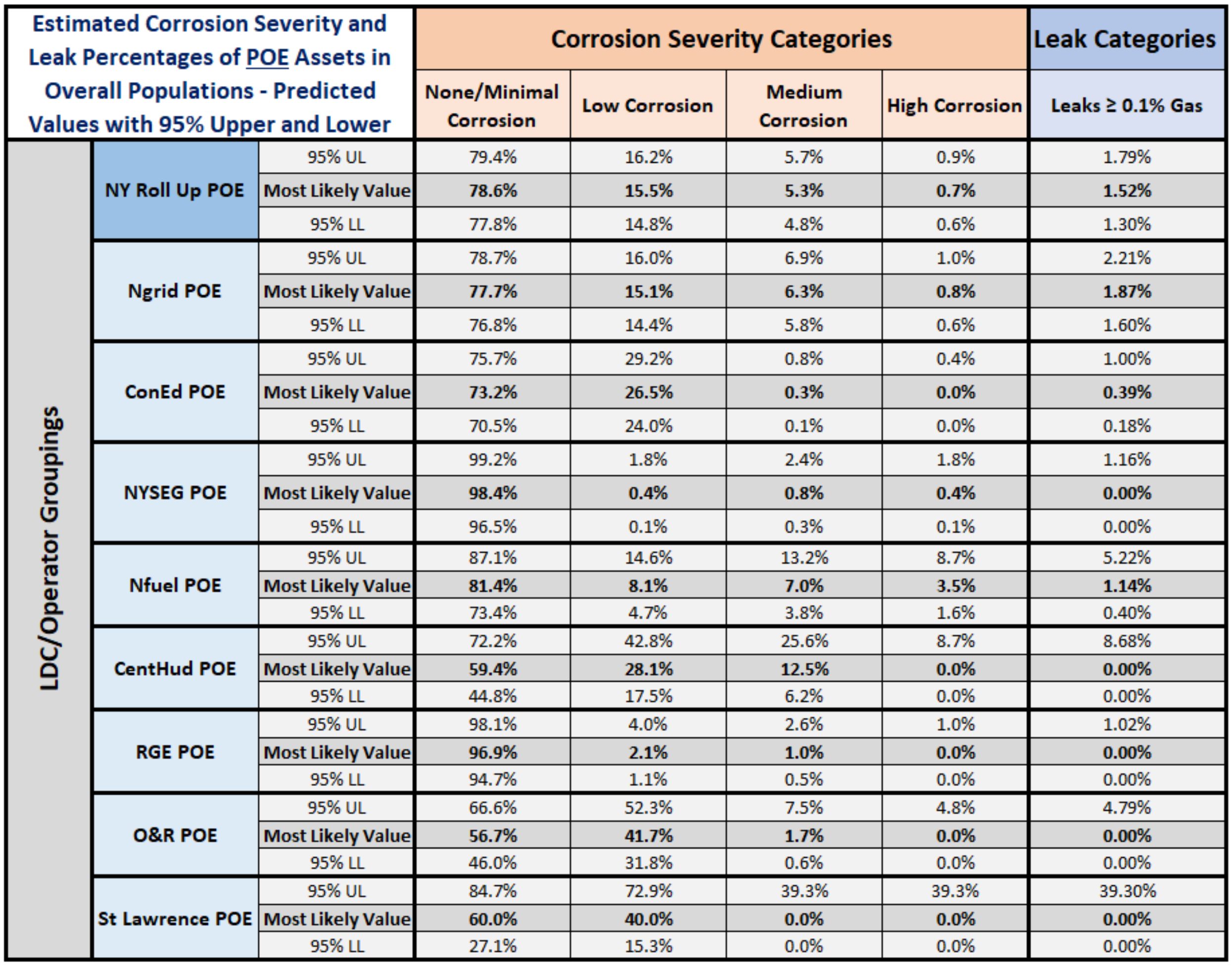
	NY Roll Up Indoor	Ngrid Indoor	ConEd Indoor	NYSEG Indoor	Nfuel Indoor	CentHud Indoor	RGE Indoor	O&R Indoor	St Lawrence Indoor
UL	0.4%	0.9%	0.1%	1.2%	3.2%	8.7%	1.0%	4.7%	13.9%
• MLV	0.3%	0.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LL	0.2%	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Figure 61. Predicted Percent of Indoor Assets Exhibiting a Leak Indication ≥ 0.1% Gas by Operator

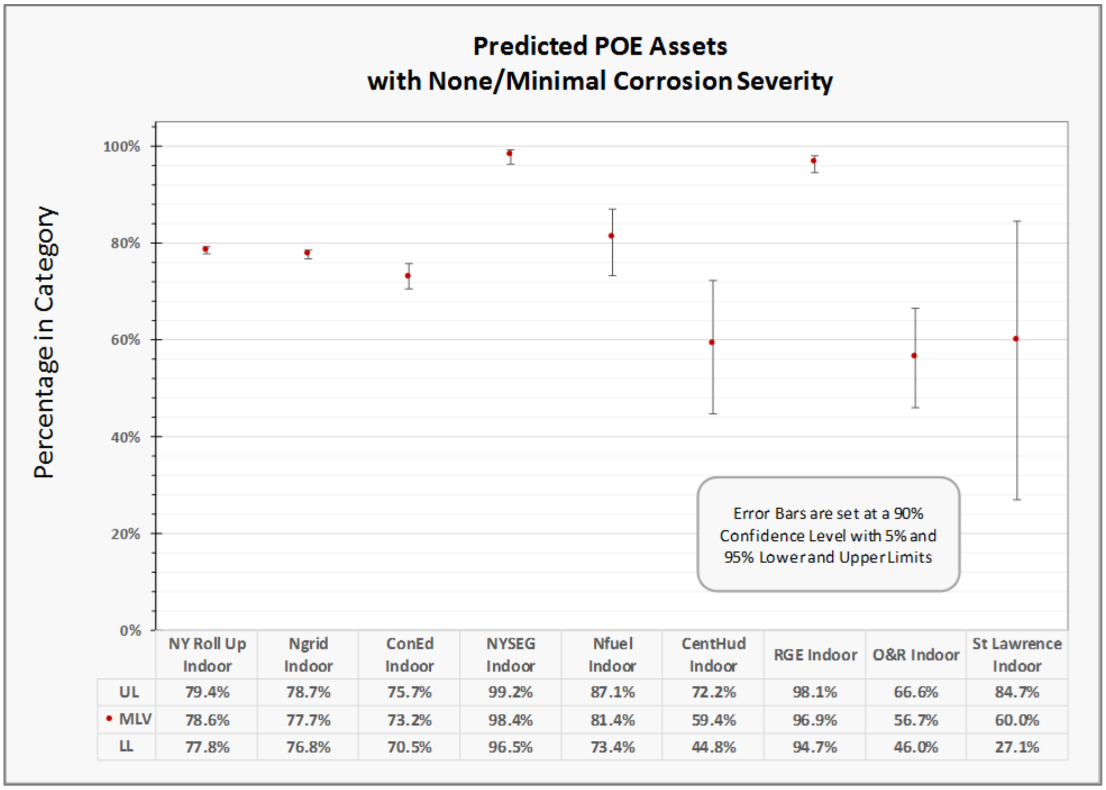
6.3 POE Assets - By NY Operators

The same type of probabilistic analysis was completed for POE assets only by NY operator, along with a NY operator combined roll-up. The predictions for the NY asset indoor population are shown in Table 18 and graphically in Figure 62 to Figure 66.

Table 18. Population Predictions for POE Asset Corrosion Severity and Leak Levels - By Operator

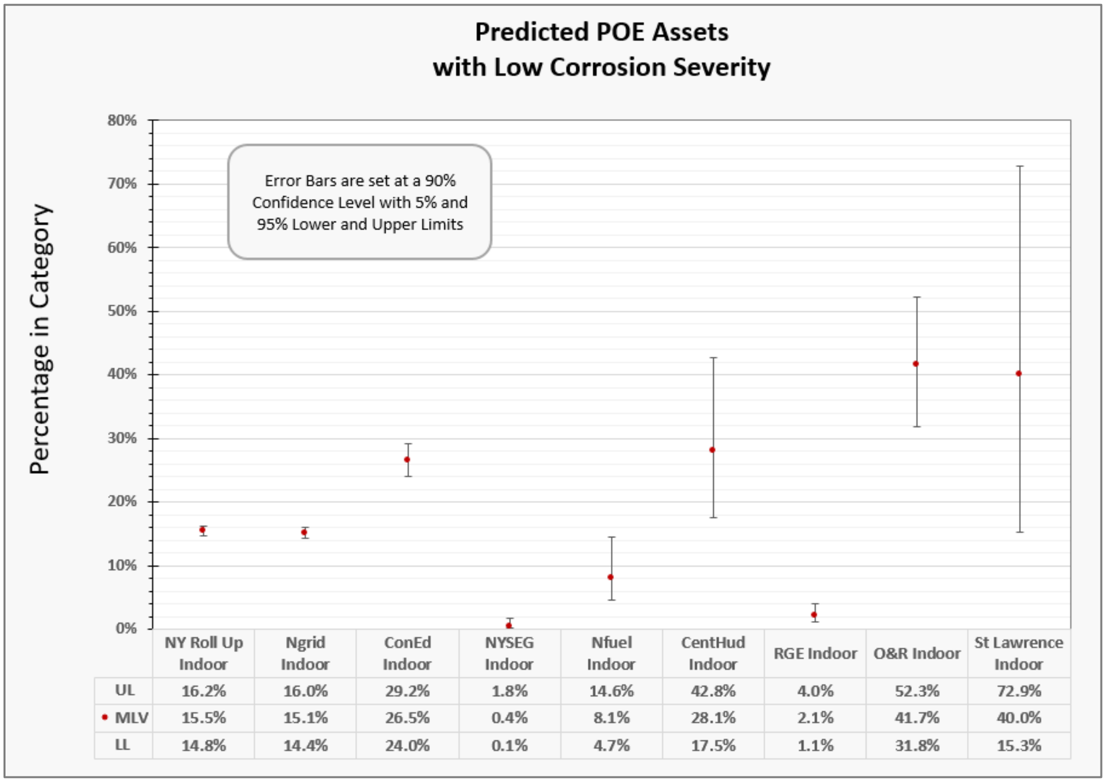


Estimated Corrosion Severity and Leak Percentages of POE Assets in Overall Populations - Predicted Values with 95% Upper and Lower			Corrosion Severity Categories				Leak Categories
			None/Minimal Corrosion	Low Corrosion	Medium Corrosion	High Corrosion	Leaks ≥ 0.1% Gas
LDC/Operator Groupings	NY Roll Up POE	95% UL	79.4%	16.2%	5.7%	0.9%	1.79%
		Most Likely Value	**78.6%**	**15.5%**	**5.3%**	**0.7%**	**1.52%**
		95% LL	77.8%	14.8%	4.8%	0.6%	1.30%
	Ngrid POE	95% UL	78.7%	16.0%	6.9%	1.0%	2.21%
		Most Likely Value	**77.7%**	**15.1%**	**6.3%**	**0.8%**	**1.87%**
		95% LL	76.8%	14.4%	5.8%	0.6%	1.60%
	ConEd POE	95% UL	75.7%	29.2%	0.8%	0.4%	1.00%
		Most Likely Value	**73.2%**	**26.5%**	**0.3%**	**0.0%**	**0.39%**
		95% LL	70.5%	24.0%	0.1%	0.0%	0.18%
	NYSEG POE	95% UL	99.2%	1.8%	2.4%	1.8%	1.16%
		Most Likely Value	**98.4%**	**0.4%**	**0.8%**	**0.4%**	**0.00%**
		95% LL	96.5%	0.1%	0.3%	0.1%	0.00%
	Nfuel POE	95% UL	87.1%	14.6%	13.2%	8.7%	5.22%
		Most Likely Value	**81.4%**	**8.1%**	**7.0%**	**3.5%**	**1.14%**
		95% LL	73.4%	4.7%	3.8%	1.6%	0.40%
	CentHud POE	95% UL	72.2%	42.8%	25.6%	8.7%	8.68%
		Most Likely Value	**59.4%**	**28.1%**	**12.5%**	**0.0%**	**0.00%**
		95% LL	44.8%	17.5%	6.2%	0.0%	0.00%
	RGE POE	95% UL	98.1%	4.0%	2.6%	1.0%	1.02%
		Most Likely Value	**96.9%**	**2.1%**	**1.0%**	**0.0%**	**0.00%**
		95% LL	94.7%	1.1%	0.5%	0.0%	0.00%
	O&R POE	95% UL	66.6%	52.3%	7.5%	4.8%	4.79%
		Most Likely Value	**56.7%**	**41.7%**	**1.7%**	**0.0%**	**0.00%**
		95% LL	46.0%	31.8%	0.6%	0.0%	0.00%
	St Lawrence POE	95% UL	84.7%	72.9%	39.3%	39.3%	39.30%
		Most Likely Value	**60.0%**	**40.0%**	**0.0%**	**0.0%**	**0.00%**
		95% LL	27.1%	15.3%	0.0%	0.0%	0.00%



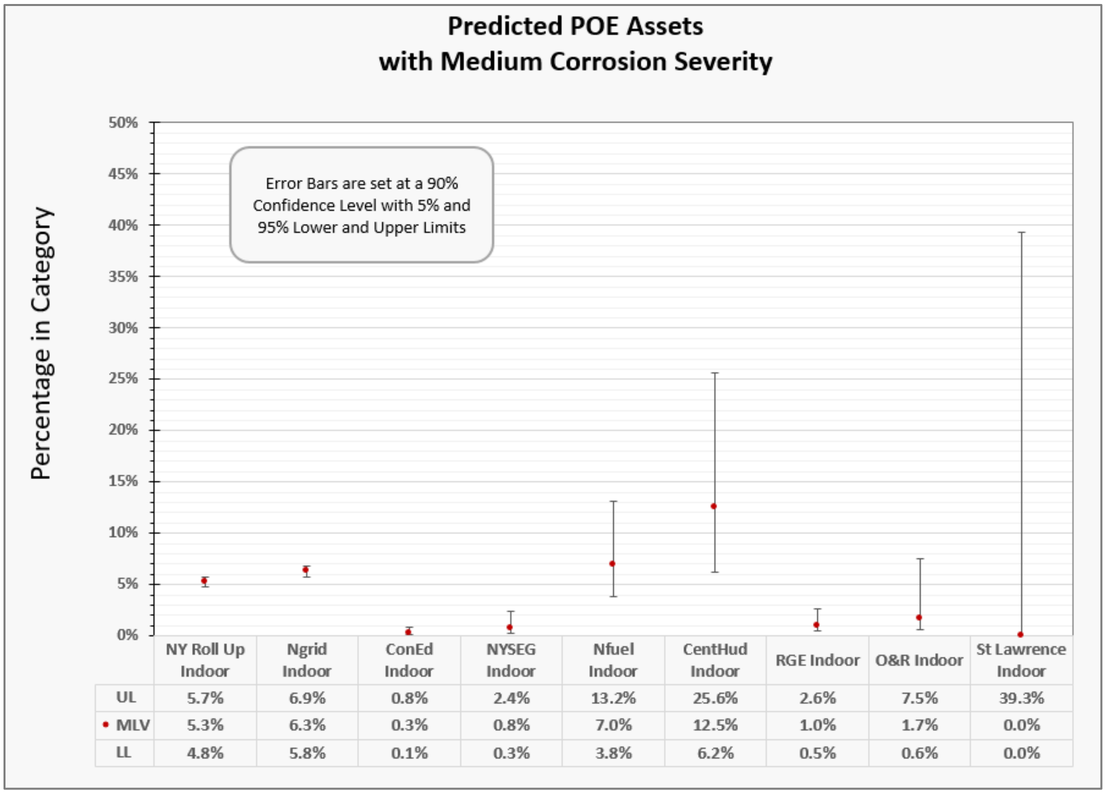
	NY Roll Up Indoor	Ngrid Indoor	ConEd Indoor	NYSEG Indoor	Nfuel Indoor	CentHud Indoor	RGE Indoor	O&R Indoor	St Lawrence Indoor
UL	79.4%	78.7%	75.7%	99.2%	87.1%	72.2%	98.1%	66.6%	84.7%
• MLV	78.6%	77.7%	73.2%	98.4%	81.4%	59.4%	96.9%	56.7%	60.0%
LL	77.8%	76.8%	70.5%	96.5%	73.4%	44.8%	94.7%	46.0%	27.1%

Figure 62. Predicted Percent of POE Assets Exhibiting a None/Minimal Corrosion Severity by Operator



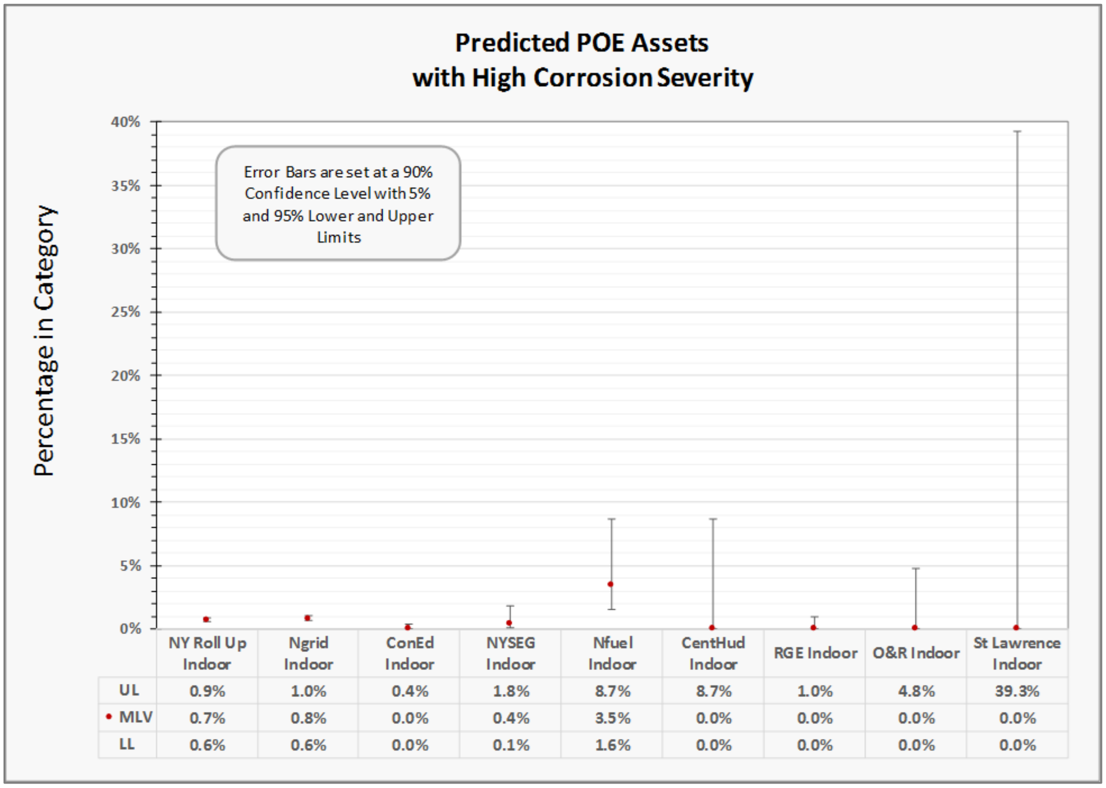
	NY Roll Up Indoor	Ngrid Indoor	ConEd Indoor	NYSEG Indoor	Nfuel Indoor	CentHud Indoor	RGE Indoor	O&R Indoor	St Lawrence Indoor
UL	16.2%	16.0%	29.2%	1.8%	14.6%	42.8%	4.0%	52.3%	72.9%
• MLV	15.5%	15.1%	26.5%	0.4%	8.1%	28.1%	2.1%	41.7%	40.0%
LL	14.8%	14.4%	24.0%	0.1%	4.7%	17.5%	1.1%	31.8%	15.3%

Figure 63. Predicted Percent of POE Assets Exhibiting a Low Corrosion Severity by Operator



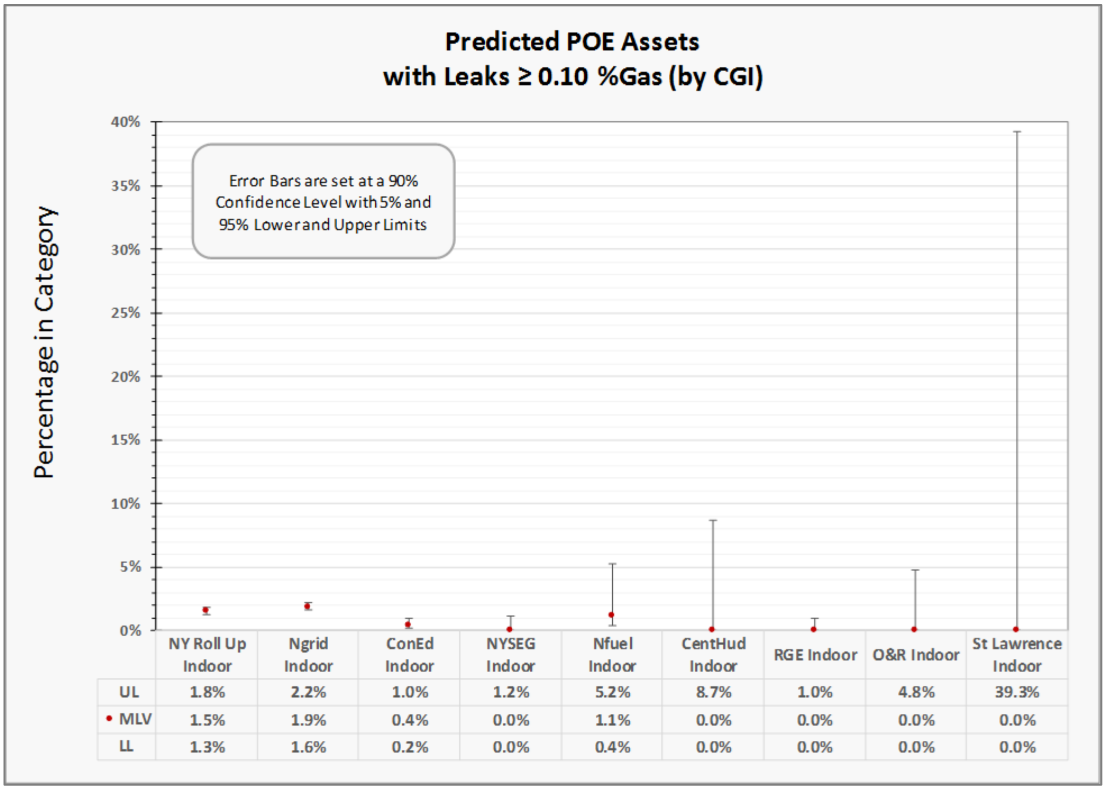
	NY Roll Up Indoor	Ngrid Indoor	ConEd Indoor	NYSEG Indoor	Nfuel Indoor	CentHud Indoor	RGE Indoor	O&R Indoor	St Lawrence Indoor
UL	5.7%	6.9%	0.8%	2.4%	13.2%	25.6%	2.6%	7.5%	39.3%
• MLV	5.3%	6.3%	0.3%	0.8%	7.0%	12.5%	1.0%	1.7%	0.0%
LL	4.8%	5.8%	0.1%	0.3%	3.8%	6.2%	0.5%	0.6%	0.0%

Figure 64. Predicted Percent of POE Assets Exhibiting a Medium Corrosion Severity by Operator



	NY Roll Up Indoor	Ngrid Indoor	ConEd Indoor	NYSEG Indoor	Nfuel Indoor	CentHud Indoor	RGE Indoor	O&R Indoor	St Lawrence Indoor
UL	0.9%	1.0%	0.4%	1.8%	8.7%	8.7%	1.0%	4.8%	39.3%
• MLV	0.7%	0.8%	0.0%	0.4%	3.5%	0.0%	0.0%	0.0%	0.0%
LL	0.6%	0.6%	0.0%	0.1%	1.6%	0.0%	0.0%	0.0%	0.0%

Figure 65. Predicted Percent of POE Assets Exhibiting a High Corrosion Severity by Operator



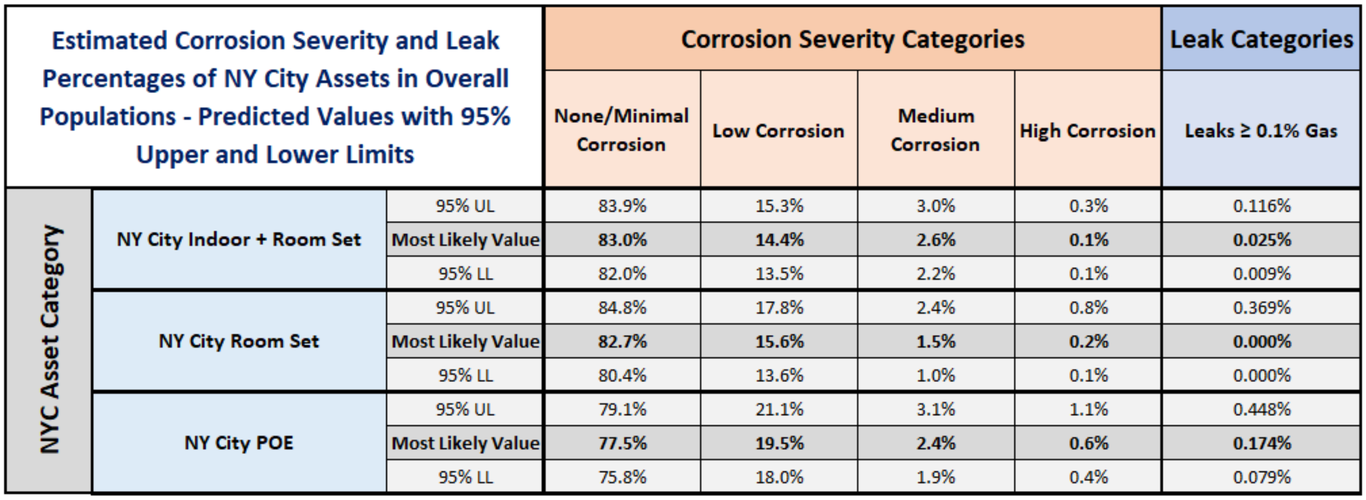
	NY Roll Up Indoor	Ngrid Indoor	ConEd Indoor	NYSEG Indoor	Nfuel Indoor	CentHud Indoor	RGE Indoor	O&R Indoor	St Lawrence Indoor
UL	1.8%	2.2%	1.0%	1.2%	5.2%	8.7%	1.0%	4.8%	39.3%
• MLV	1.5%	1.9%	0.4%	0.0%	1.1%	0.0%	0.0%	0.0%	0.0%
LL	1.3%	1.6%	0.2%	0.0%	0.4%	0.0%	0.0%	0.0%	0.0%

Figure 66. Predicted Percent of POE Assets Exhibiting a Leak Indication ≥ 0.1% Gas by Operator

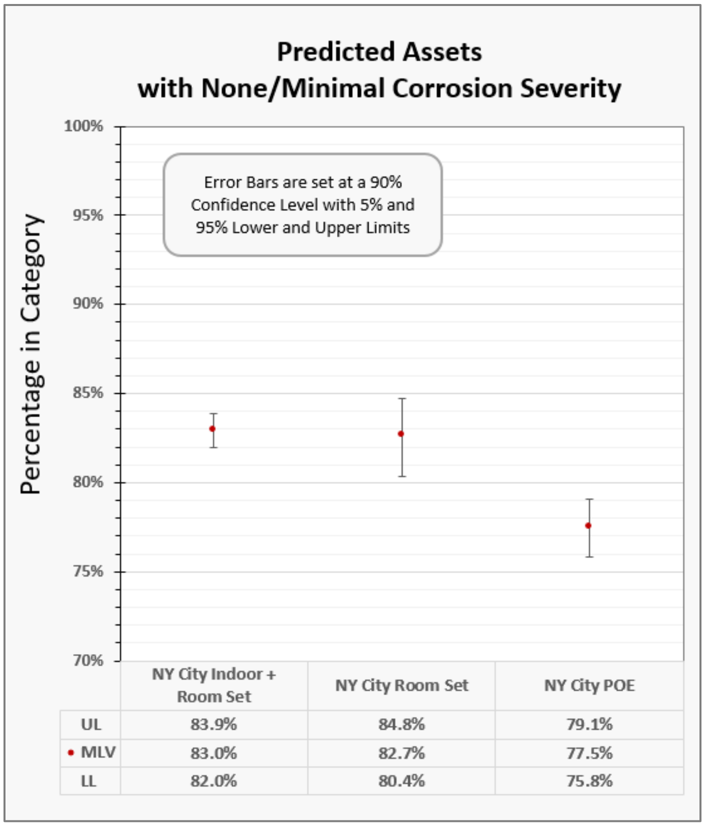
6.4 Assets - New York City (NYC) Only Population of Survey Sites

The same type of probabilistic analysis was completed for NY City assets. The predictions for the NY city assets are shown in Table 19 and graphically in Figure 67 to Figure 71.

Table 19. Population Predictions for Corrosion Severity and Leak Levels - NY City Roll Up

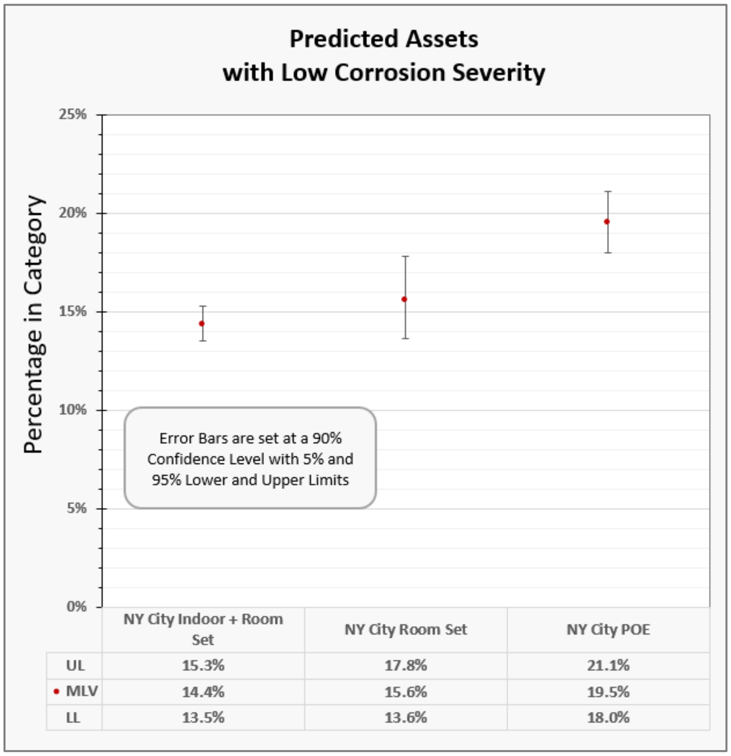


Estimated Corrosion Severity and Leak Percentages of NY City Assets in Overall Populations - Predicted Values with 95% Upper and Lower Limits			Corrosion Severity Categories				Leak Categories
			None/Minimal Corrosion	Low Corrosion	Medium Corrosion	High Corrosion	Leaks ≥ 0.1% Gas
NYC Asset Category	NY City Indoor + Room Set	95% UL	83.9%	15.3%	3.0%	0.3%	0.116%
		Most Likely Value	**83.0%**	**14.4%**	**2.6%**	**0.1%**	**0.025%**
		95% LL	82.0%	13.5%	2.2%	0.1%	0.009%
	NY City Room Set	95% UL	84.8%	17.8%	2.4%	0.8%	0.369%
		Most Likely Value	**82.7%**	**15.6%**	**1.5%**	**0.2%**	**0.000%**
		95% LL	80.4%	13.6%	1.0%	0.1%	0.000%
	NY City POE	95% UL	79.1%	21.1%	3.1%	1.1%	0.448%
		Most Likely Value	**77.5%**	**19.5%**	**2.4%**	**0.6%**	**0.174%**
		95% LL	75.8%	18.0%	1.9%	0.4%	0.079%



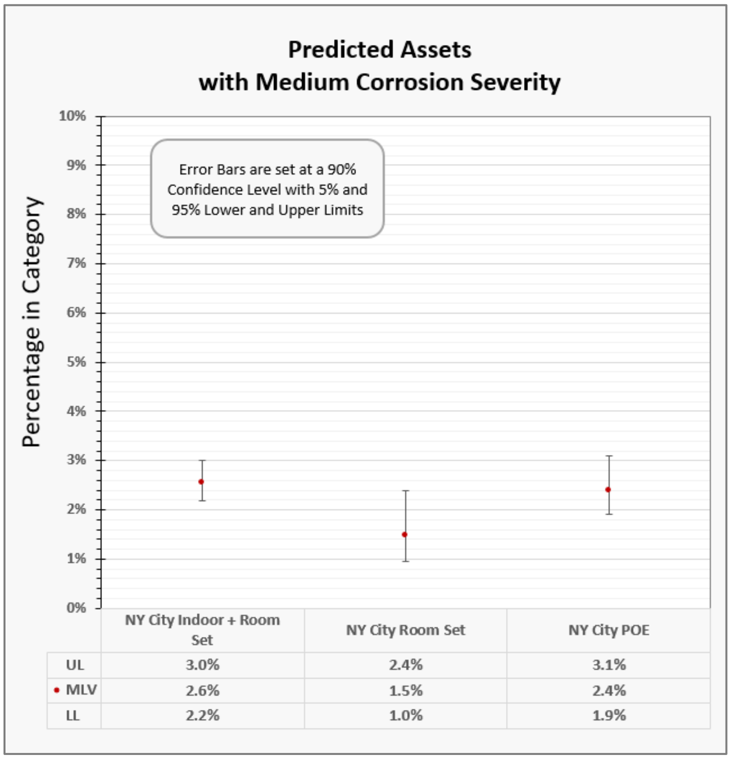
	NY City Indoor + Room Set	NY City Room Set	NY City POE
UL	83.9%	84.8%	79.1%
• MLV	83.0%	82.7%	77.5%
LL	82.0%	80.4%	75.8%

Figure 67. Predicted Percent of NY City Assets Exhibiting a None/Minimal Corrosion Severity



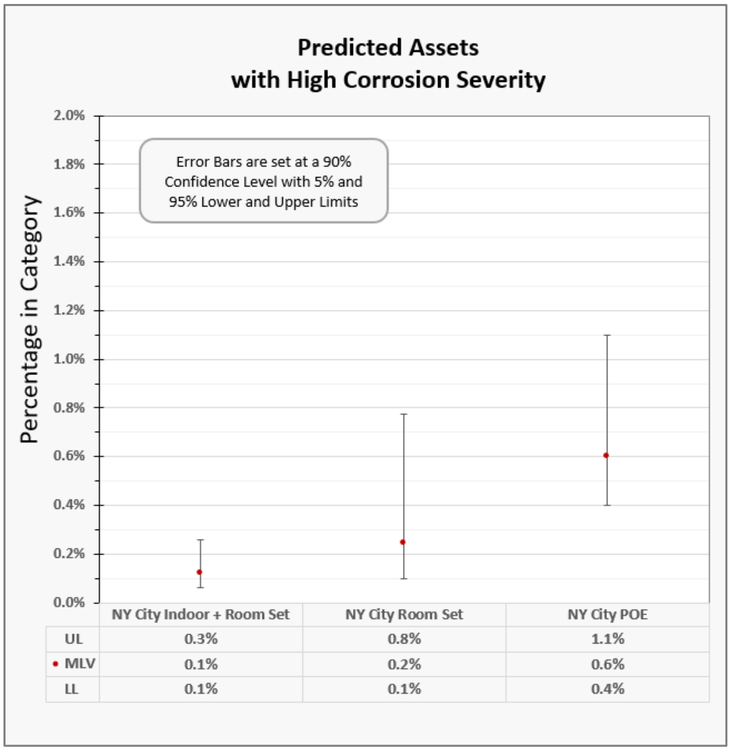
	NY City Indoor + Room Set	NY City Room Set	NY City POE
UL	15.3%	17.8%	21.1%
• MLV	14.4%	15.6%	19.5%
LL	13.5%	13.6%	18.0%

Figure 68. Predicted Percent of NY City Assets Exhibiting a Low Corrosion Severity



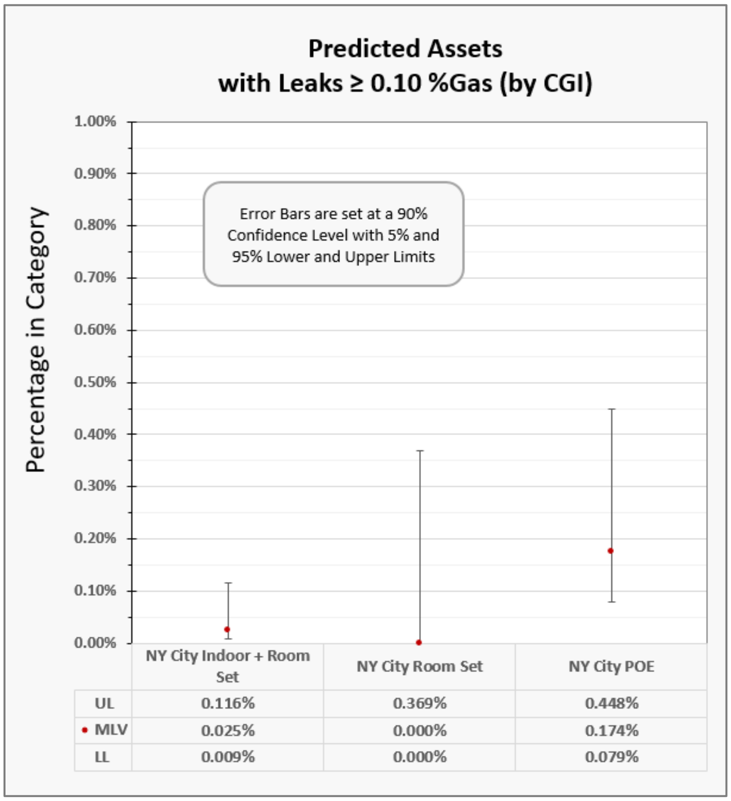
	NY City Indoor + Room Set	NY City Room Set	NY City POE
UL	3.0%	2.4%	3.1%
• MLV	2.6%	1.5%	2.4%
LL	2.2%	1.0%	1.9%

Figure 69. Predicted Percent of NY City Assets Exhibiting a Medium Corrosion Severity



	NY City Indoor + Room Set	NY City Room Set	NY City POE
UL	0.3%	0.8%	1.1%
• MLV	0.1%	0.2%	0.6%
LL	0.1%	0.1%	0.4%

Figure 70. Predicted Percent of NY City Assets Exhibiting a High Corrosion Severity



Error Bars are set at a 90% Confidence Level with 5% and 95% Lower and Upper Limits

	NY City Indoor + Room Set	NY City Room Set	NY City POE
UL	0.116%	0.369%	0.448%
• MLV	0.025%	0.000%	0.174%
LL	0.009%	0.000%	0.079%

Figure 71. Predicted Percent of NY City Assets Exhibiting a Leak Indication ≥ 0.1% Gas

7 Conclusions

The programmatic sampling effort was conducted over approximately a one year period in 2016 to address typical indoor environmental operating variables an operator may experience in day-to-day operations. This strategic approach allowed for an adequate set of random inspection sampling of the New York and New Jersey operator's indoor atmospheric systems throughout one complete cycle of seasons. A total of nine New York and one New Jersey operator participated in the random corrosion and leak surveys. All the operators, with the exception of the New Jersey operator classified their sample sites as indoor, room sets, or building point-of-entry (POE). Since the full protocol was not followed by the New Jersey company, data and analysis is located separately in the Appendix B of this report. The body of the report is applicable to the state of New York.

A properly designed random sampling plan coupled with statistical analysis was carried out to determine the probability and severity (with confidence levels) of indoor, atmospheric corrosion and leak survey results as a function of system attributes and location. The sampling plan was designed to ensure an unbiased randomly selected set of locations representative of NY State operating areas. Operating variables considered in plan design and sample selection included rural/urban vs. coastal/industrial areas; year of installation; conditioned vs. non-conditioned spaces; meters above and below grade; commercial, multi-unit, and single unit sites; point-of-entry piping, meter rooms, and room sets; and vented vs. non-vented spaces. The random sample was vital to ensure that conditional probability analysis could be conducted to infer the sample results to the broader population, thereby allowing for the calculation of confidence limits on predictions that take into account uncertainty.

A comprehensive, standardized protocol for conducting both atmospheric corrosion inspections and indoor piping leak surveys was developed and implemented. Atmospheric corrosion visual comparators/guides and step-by-step checklists were provided to the operators, along with a standardized spreadsheet to collect and submit their survey results. The protocol ensured a standard and repeatable approach to grading indoor asset corrosion severity and assessing any indoor piping leak indications. Leak surveys were conducted utilizing a combustible gas indicator, with a threshold detection limit of 0.1% gas-in-air (typical instruments used to perform indoor piping leak investigations).

A total of 15,505 random indoor corrosion and leak surveys were completed. This is a very large number of data points which allowed for the selection of high confidence levels of 90% to 95% when inferring the sample results to the broader NY or even operator-by-operator indoor asset population.

The results of the random surveys were analyzed by the variables recorded for each inspection, and showed there were approximately 61% of the sites conditioned and 39%

unconditioned; 83% were in urban or rural geographic locations and 17% in coastal or industrial locations; about 54% of the sites were at the building point-of-entry (POE) penetration and for the other 46% of survey sites the meter locations were near the POE in about 48% of the cases; 28% were pre-1965, 34% 1965-1990, and 38% post 1990 installations, 44% were single family dwellings, 48% multi-unit, and 8% commercial or industrial sites.

Descriptive statistics were calculated for environmental variables measured at each inspection site (temperature and relative humidity), as well as the individual site system pressures. The temperature and relative humidity levels measured over the sampling year of 2016 were normally distributed and representative of past indoor corrosion studies that covered the NY area.

The corrosion severity (four levels) and number of leak indications (based on a 0.1% Gas threshold) were analyzed for the random survey set and summaries by NY State (all NY Operators combined) and by individual operator. The survey results were also reported out in sub-groups such as: indoor meters and piping (with and without room sets), building point-of-entry (POE) penetration, and also for room sets alone.

The high-level summary shows that for corrosion severity there were 80.7% with none/minimal corrosion, 14.5% low corrosion, 4.3% medium corrosion, and less than 1% with high corrosion levels. The proportion of the samples related to leak indications showed that 99% of the sites exhibited no leak indications while less than 1% had an indication of a leak with a median leak indication concentration level of 0.15% Gas.

The analysis of indoor meters and piping vs. the building POE penetration locations showed that for indoor meter and associated piping (non-POE) sites 12 of 5,752 (or 0.21%) had high corrosion severity and 16 of 5,757 (or 0.28%) exhibited leak indications at 0.1% Gas or higher. Whereas, for building POE penetration locations 48 of 6,897 (or 0.70%) had high corrosion severity and 104 of 6,841 (or 1.52%) leak indications at 0.1% Gas or higher. On a relative basis, 48 sites of the 60 high corrosion sites (or 80%) and 104 out of the 120 leak indications sites (or 87%) were in the building POE penetration locations. This illustrates greater propensity for potential corrosion and leak indications at building POE penetration sites.

A variable sensitivity analysis was conducted to determine what variables correlated to observed corrosion severity and leak indications. The categorical levels for corrosion and leak indication were assigned an ordinal number that was used to calculate average values for corrosion and leak indexes. A comparison of means (averages) was conducted for each variable category to determine if there was a statistical difference between it and the remaining categories for the variable. This was supplemented with an analysis of variation (ANOVA) regression analysis to confirm the significant variables (inclusive of all categories) as related to the corrosion and leak indications. Based on these two sensitivity checks, the variable categories that correlated to higher corrosion or increased leak indications were noted. Those categories that did not show statistical difference between their mean index levels and all the remaining categories for the variable were coded as being neutral. The five "sensitive" variable categories for Corrosion (and only four of the five for Leak Indications) that correlated to increased average corrosion and leak index values:

- Non-Conditioned Spaces
- Urban/Rural Geographic Locations
- Below Grade Asset Location
- Commercial/Multi-Unit Dwelling Type (for Corrosion Severity only)
- Meter Location within Building (i.e., indoor meters and piping near the POE location)

In addition to this sensitivity analysis on the variables, the comparison of results, i.e. comparing corrosion severity levels to leak indications, showed that leak indication locations had on average a 21% higher corrosion severity index with a significant separation of the mean confidence intervals.

Conditional probability analysis was used to calculate the probable corrosion severity and leak indication levels for each major category of assets in the entire NY (and by operator) indoor, aboveground asset *population* from where the random *sample* was drawn. These predictions include the most likely proportions of corrosion severity and leak indication rates along with lower and upper confidence limits that reflect the uncertainty in the predictions.

An additional probabilistic analysis was performed on a statistically significant number of leak indications, above and below the 0.1% Gas threshold, which were measured with both an ordinary hand-held CGI (with sample probe) and belt clip CGI detector (without sample probe). The true and false negative and positive indications showed significant variations between the belt clip sampling technique and traditional CGI measurements techniques within a confidence level of 96%.

The results of the sensitivity analysis were relatively ranked and prepared into a table that matches installation attributes (aka variable categories) for indoor meter and piping to a relative severity weight. The relative weights for each installation attribute variable can be added for an overall "likelihood" of severe corrosion/leak indication weighting. This overall likelihood severity weight can be multiplied with an operator-assigned consequence relative weighting to provide a relative risk weighting.

A relative weighting scale was developed based on the random sampling analysis that assigns a number from 1 to 15 (lower to higher likelihood risk) for each of the random sample variables that exhibited correlation to corrosion severity and leak indications.

The variable/category relative weightings and the population upper confidence limit proportions can be used as part of a DIMP-based, risk-weighted indoor, aboveground corrosion and leak inspection program - both for establishing initial base-line analysis schedules and for assessing an appropriate frequency of re-inspection post completion of base-line assessments.

The statistically sound data with confidence limits from this report can be coupled with consequence considerations and guide operators to make appropriate company-by-company asset based, reasonably prioritized, base-line inspections coupled with properly set inspection intervals to maximize public safety value.

8 Appendix A – NY CGI Leak Indication Survey Measurement Histograms and Descriptive Statistics

The leak indication data was captured on a continuous scale (CGI readings) so it can be analyzed with descriptive statistics. The corrosion severity was graded categorically.

8.1 NY Operator Leak Indications at ≥ 0.1% Gas

The leak indication data was analyzed. Leaks are defined as % Gas readings ≥ 0.1 % on CGI for any piping and components upstream of the meter outlet. A histogram of the data is shown below the table. The data is presented with NY Operators combined. The PSE&G (NJ) leaks are analyzed in the next section.

There were **120 total** leak indications from NY Operators that were ≥ 0.1% Gas. Six (6) of the leak indications noted were room set meters. Out of the 120 total leak indications 104 were at building POE penetrations and 16 were Indoor Meters/ piping.

1. **NGrid - 116** * leak indications
    a. **115** leak indications are from **NIMO**
        i. 100 leaks are building POE penetrations
        ii. 15 leaks are Indoor Meter/Piping
    b. **1** leak is from **NYC** and is Indoor Meter/Piping
2. **ConEd - 3** leaks all POE
3. **NFuel - 1** leak is POE

* **Note** for NGrid: there are 118 total leak indications when one filter's the raw data, but two are not applicable and should not be counted – so there are 116:

- There is a leak that is **0.6623% Gas** in NGrid/KEDLI that is in an Oven – so this was not included.
- There is a leak in NYC that was **2.3% Gas** that was not confirmed by the CGI follow-up so it was not included.

The descriptive statistics for these leaks are shown in Table 20 and Figure 72 below.

Table 20. Leak Indication Analysis (≥ 0.1%Gas) from Random Sampling - All NY Operators

Leak Indication Survey Summary	Statistic
Number of Inspection Sites (of 12,598) with Leaks ≥ 0.1% Gas	120
Mean % Gas	0.35 %
Median % Gas	0.15 %
Min % Gas	0.10 %
Max % Gas	6.00 %
25 percentile % Gas	0.10 %
75 percentile % Gas	0.25 %

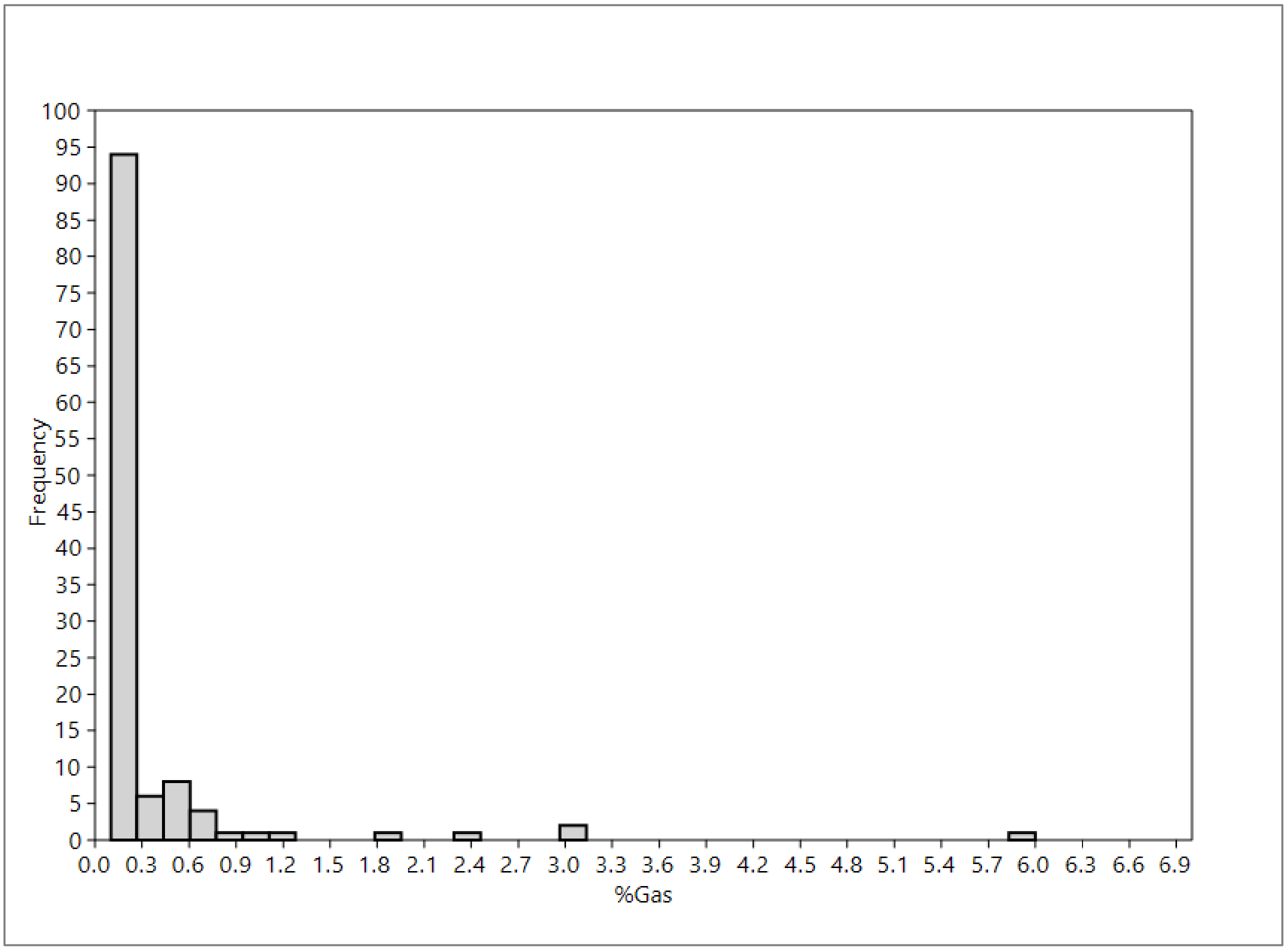


Figure 72. Histogram of the Identified Leaks at least 0.1% Gas from NY Operators Only

8.2 NY Operator Leak Indications < 0.1% Gas

There were **110 total** leaks from NY Operators that were < 0.1% Gas. Four (4) leaks noted meters were room sets. Of the 110 total leaks, 99 were POE and 11 Indoor.

NGrid - **110** leak indications
  105 leak indications are from **NIMO**
    96 leaks are building POE penetrations
    9 leaks are Indoor Meters/Piping
  1 leak indication is from **NYC** and is a building POE penetration
  4 leak indications are from **KEDLI** and 2 are building POE penetrations and 2 are Indoor Meters/Piping

The descriptive statistics for these leak indications are shown in Table 21 and Figure 73 below.

Table 21. Leak Indication Analysis (< 0.1%Gas) from Random Sampling - All NY Operators

Leak Indication Survey Summary	Statistic
Number of Inspection Sites (of 12,598) with Leak Indications < 0.1% Gas	110
Mean % Gas	0.05 %
Median % Gas	0.05 %
Min % Gas	0.007 %
Max % Gas	0.075 %
25 percentile % Gas	0.05 %
75 percentile % Gas	0.05 %

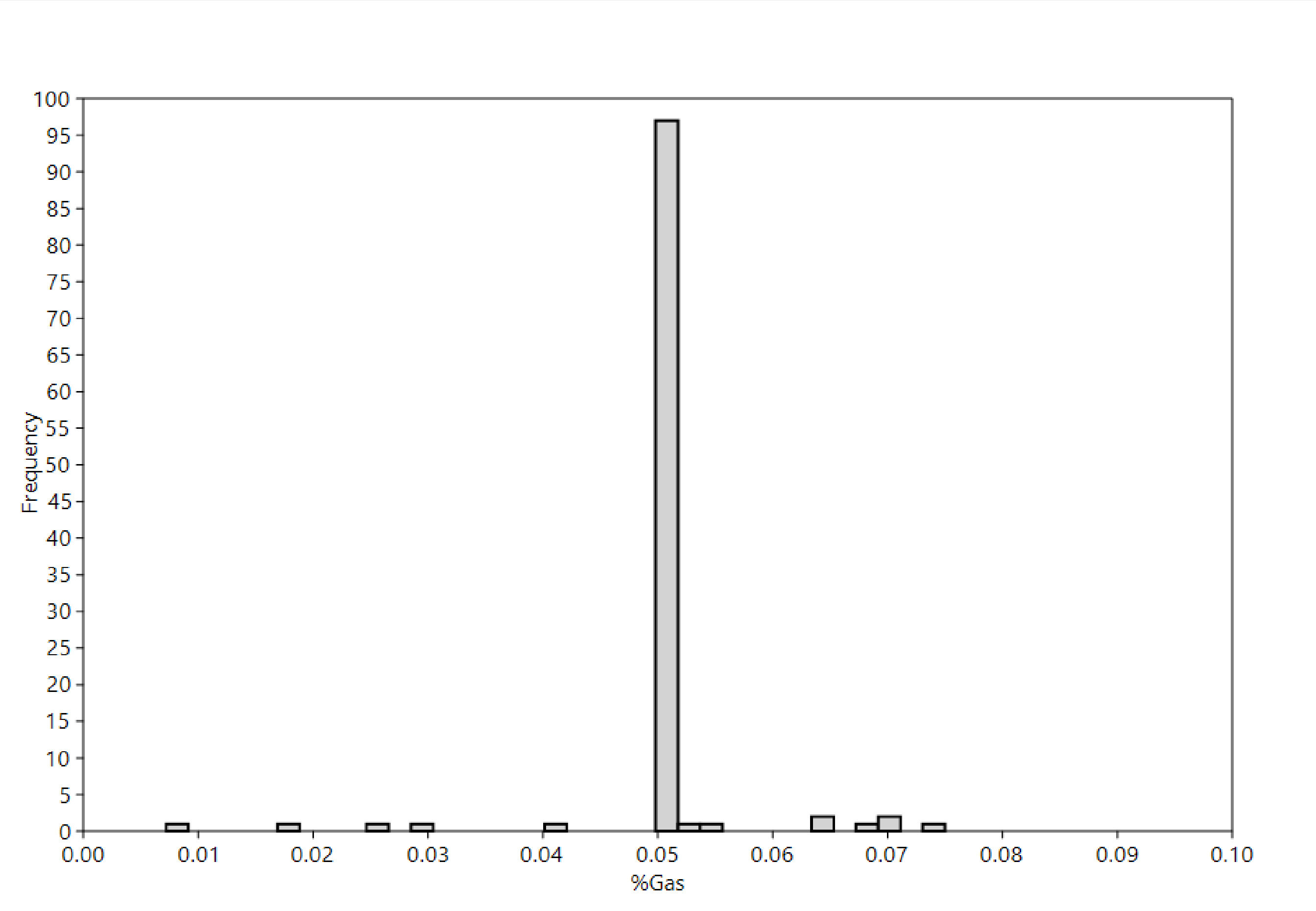


Figure 73. Histogram of the Identified Leak Indications < 0.1% Gas from NY Operators Only

9 Appendix B – New Jersey (PSE&G) Limited Data Set and Analysis

9.1 New Jersey (PSE&G) Limited Survey Results

See the body of the report for explanations of the tables and plots in this Appendix section.

Table 22. Corrosion and Leak Inspection Summary for PSE&G

Random Inspection Corrosion and Leak Survey Roll Up	PSE&G	
Corrosion Summary	**Numbers**	**Percent**
None/Minimal Corrosion	2,598	98.37
Low Corrosion	23	0.87
Med Corrosion	2	0.08
High Corrosion	18	0.68
Sub-Totals	2,641	100.0
Leak Summary	**Numbers**	**Percent**
Not Leaking	2,148	95.34
Leaking (≥ 0.1% Gas on CGI)	105	4.66
Sub-Totals	2253	100.00

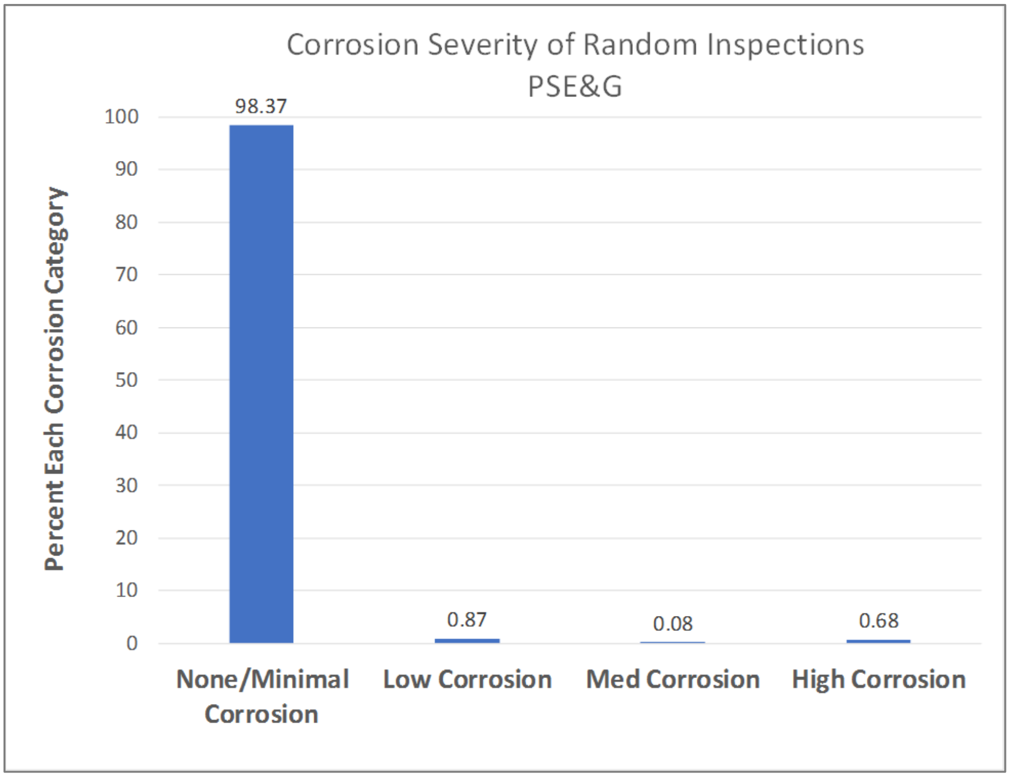


Figure 74. Corrosion Percent by Severity Category for Random Inspections for PSE&G

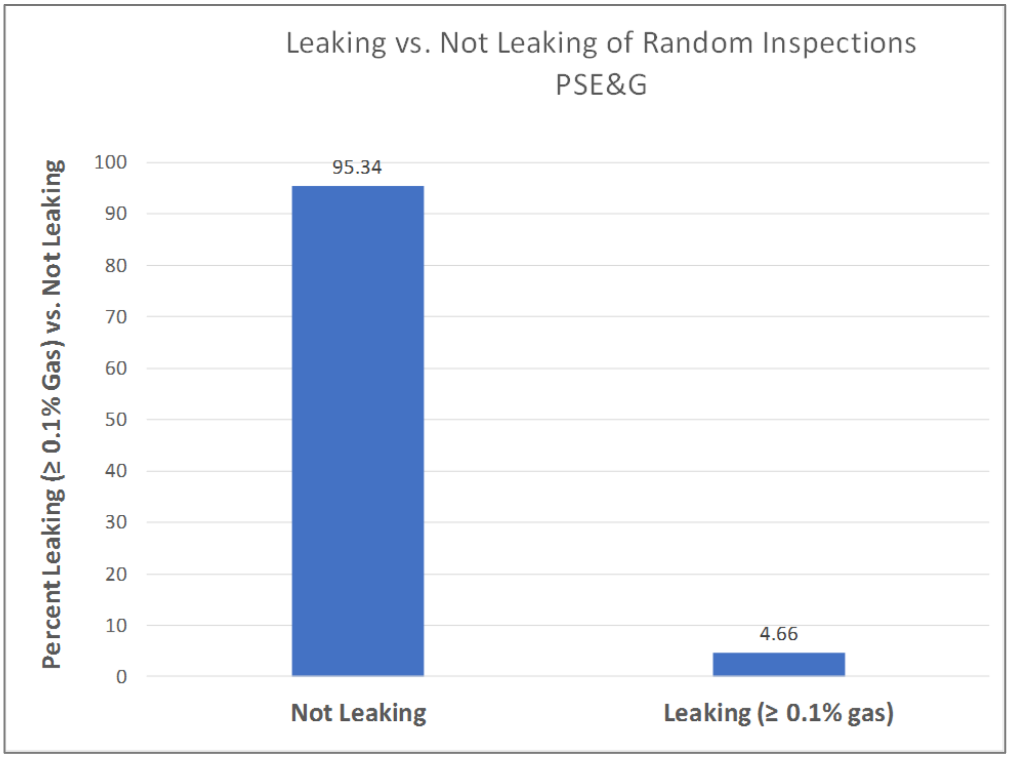


Figure 75. Leak Inspection Summary for PSE&G

9.2 Conditional Probability Analysis - Inference of Sample Results to the Broader Population

9.2.1 Corrosion and Leak Indication Roll Up Estimates

Table 23. Population Predictions for Overall Asset (Indoor and POE) Corrosion Severity and Leak Levels - PSE&G (NJ)

Estimated Corrosion Severity and Leak Percentages of Overall Population - Predicted Values with 95% Upper and Lower Limits		Corrosion Severity Categories				Leak Categories	
		None/Minimal Corrosion	Low Corrosion	Medium Corrosion	High Corrosion	Leaks ≥ 0.1% Gas	Leaks ≥ 5% Gas
PSEG (NJ) Indoor + POE	95% UL	98.7%	1.2%	0.2%	1.0%	5.46%	0.806%
	Most Likely Value	**98.4%**	**0.9%**	**0.1%**	**0.7%**	**4.66%**	**0.488%**
	95% LL	97.9%	0.6%	0.0%	0.5%	3.99%	0.307%

9.3 New Jersey (PSE&G) CGI Leak Measurement Descriptive Statistics

9.3.1 PSE&G Leaks at least at 0.1% Gas

The leak indication data was analyzed from the PSE&G data separately. PSE&G did not include all the metadata so we could not break these down between POE, Indoor, and/or Room Sets. Leak indications are defined as %Gas readings ≥ 0.1% on CGI for any piping and components upstream of the meter outlet. A histogram of the data is shown below the table.

There were **105 leak indications from PSE&G** that were ≥ 0.1% Gas.

The descriptive statistics for these leaks are shown in Table 24 and Figure 76 below.

Table 24. Leak Indication Analysis (≥ 0.1%Gas) from Random Sampling for PSE&G Only

Leak Survey Summary	Statistic
Number of Inspection Sites (of 2,253) with Leak Indications ≥ 0.1% Gas	105
Mean % Gas	1.75 %
Median % Gas	0.80 %
Min % Gas	0.10 %
Max % Gas	38.00 %
25 percentile % Gas	0.10 %
75 percentile % Gas	1.50 %

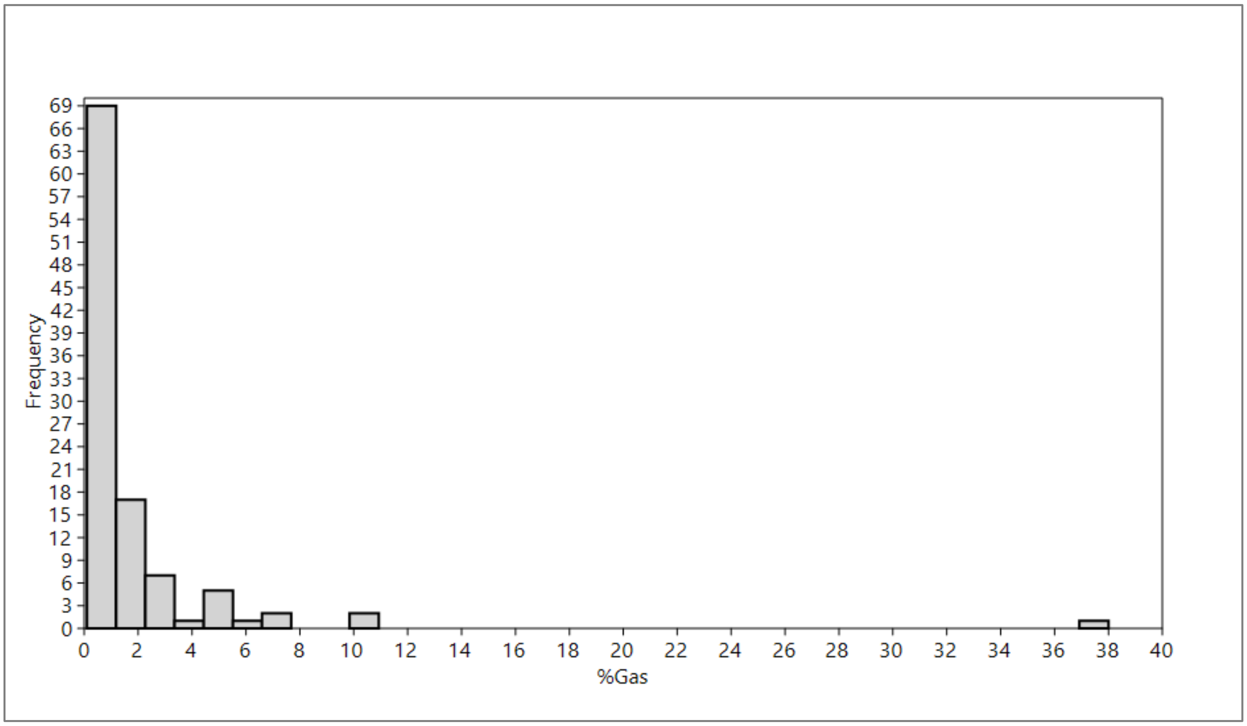


Figure 76. Histogram of the Identified Leak Indications at least 0.1% Gas from PSE&G Only

9.3.2 PSE&G Leak Indications < 0.1% Gas

There were **10 leak indications from PSE&G** that were < 0.1% Gas.

The descriptive statistics for these leak indications are shown in Table 25 and Figure 73 below.

Table 25. Leak Indication Analysis (< 0.1%Gas) from Random Sampling PSE&G Only

Leak Survey Summary	Statistic
Number of Inspection Sites (of 2,253) with Leak Indications < 0.1% Gas	10
Mean % Gas	0.05 %
Median % Gas	0.05 %
Min % Gas	0.009 %
Max % Gas	0.06 %
25 percentile % Gas	0.05 %
75 percentile % Gas	0.05 %

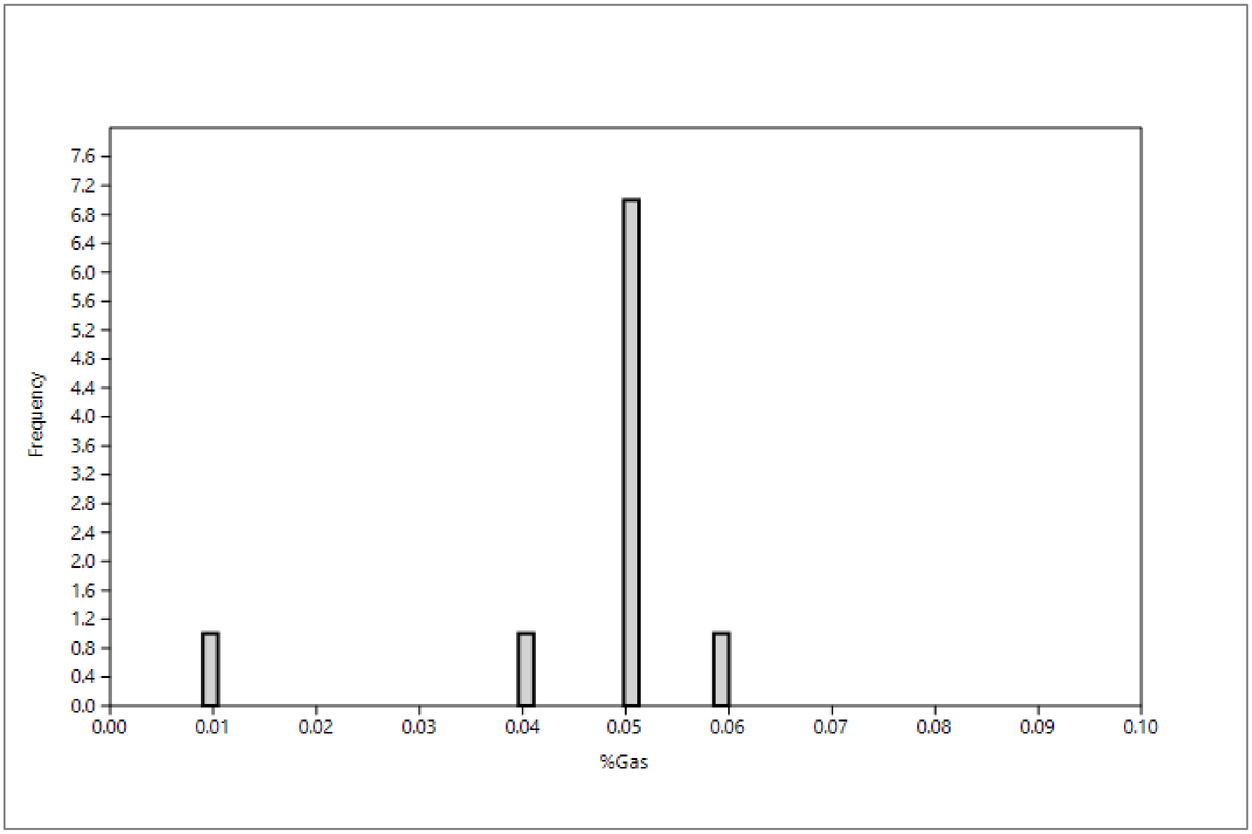
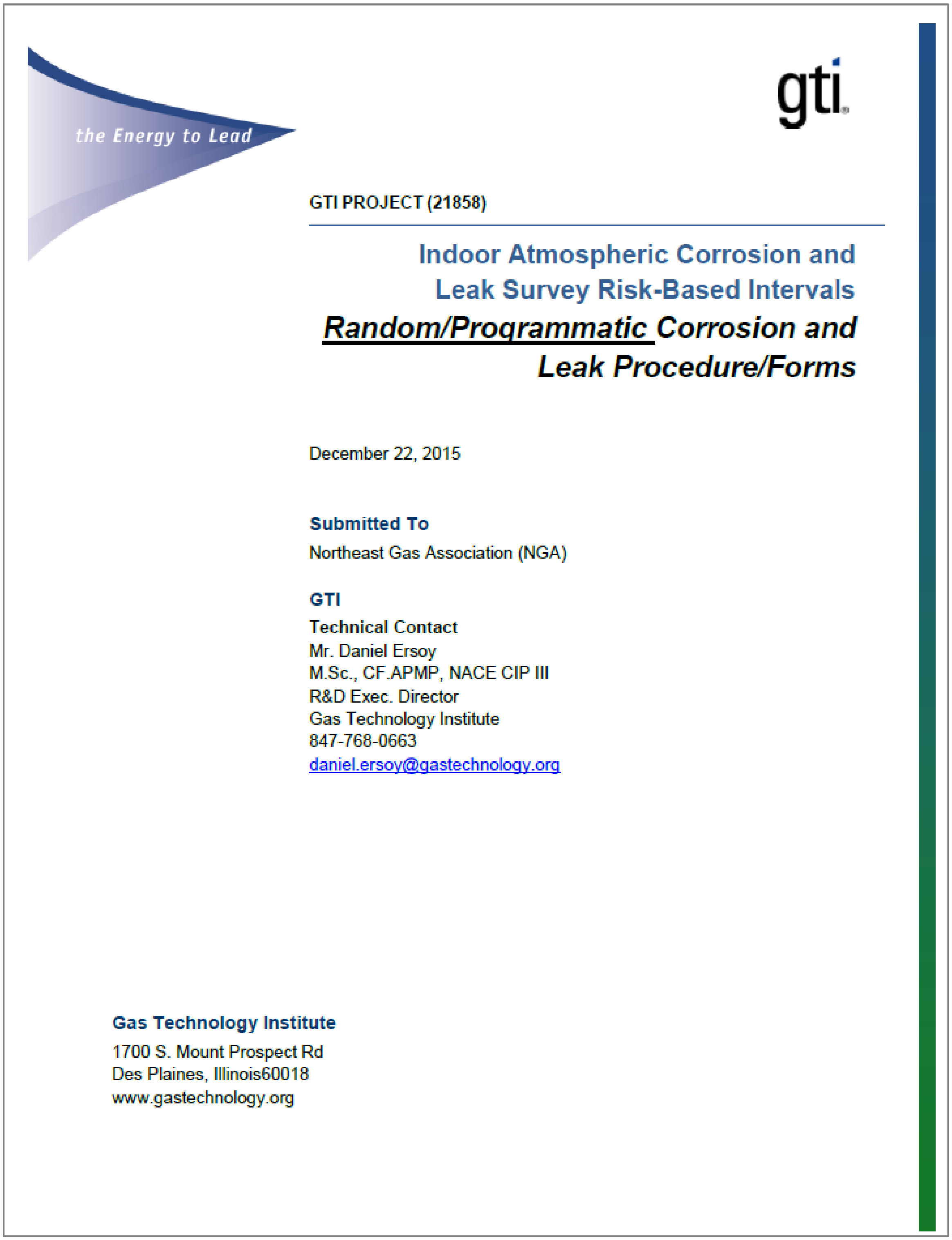


Figure 77. Histogram of the Identified Leaks < 0.1% Gas from PSE&G Only

10 Appendix C – Random Sampling Program Corrosion and Leak Survey Procedure & Forms



the Energy to Lead

GTI PROJECT (21858)

Indoor Atmospheric Corrosion and Leak Survey Risk-Based Intervals

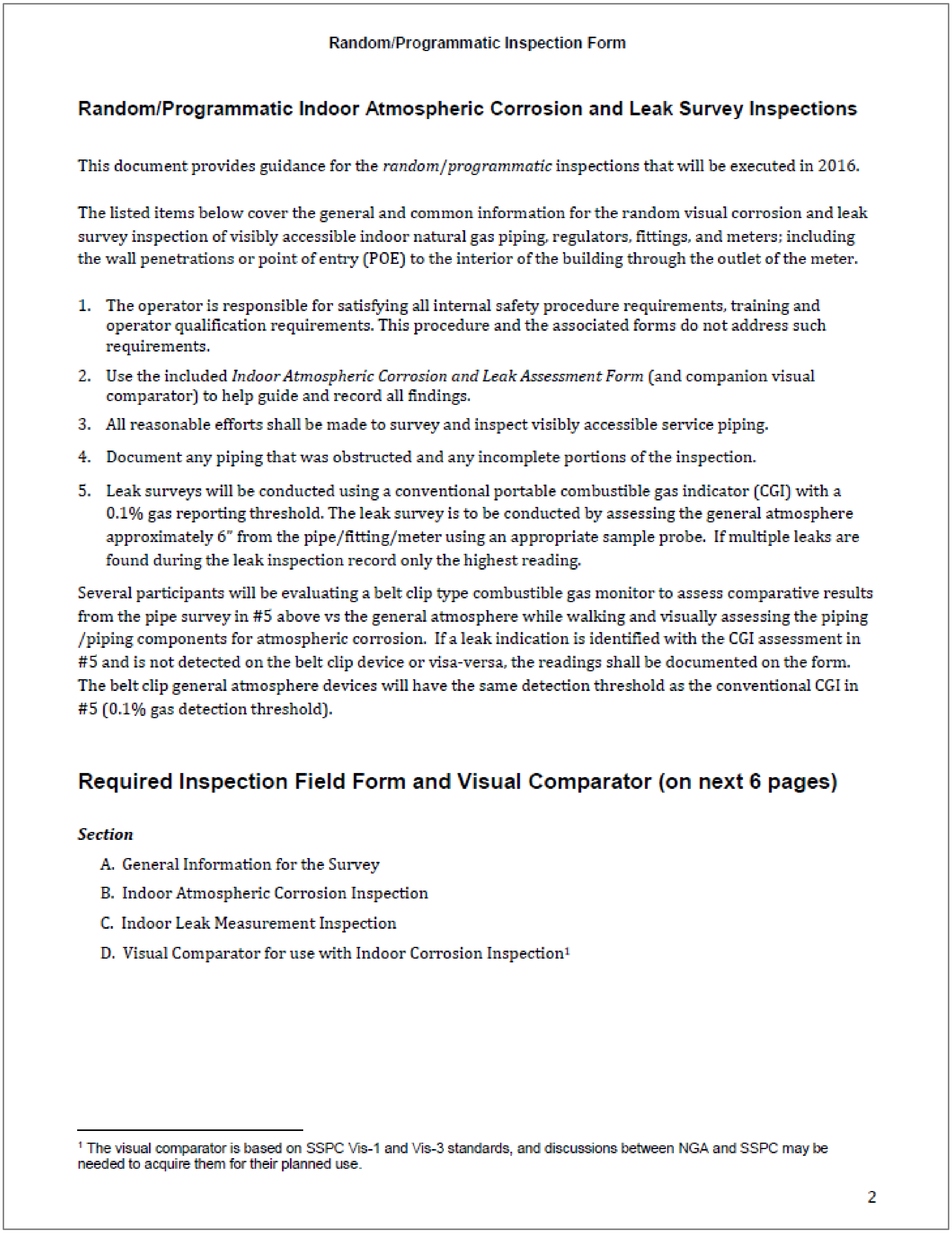
Random/Programmatic Corrosion and Leak Procedure/Forms

December 22, 2015

Submitted To
Northeast Gas Association (NGA)

GTI
Technical Contact
Mr. Daniel Ersoy
M.Sc., CF.APMP, NACE CIP III
R&D Exec. Director
Gas Technology Institute
847-768-0663
daniel.ersoy@gastechnology.org

Gas Technology Institute
1700 S. Mount Prospect Rd
Des Plaines, Illinois60018
www.gastechnology.org



Random/Programmatic Inspection Form

Random/Programmatic Indoor Atmospheric Corrosion and Leak Survey Inspections

This document provides guidance for the *random/programmatic* inspections that will be executed in 2016.

The listed items below cover the general and common information for the random visual corrosion and leak survey inspection of visibly accessible indoor natural gas piping, regulators, fittings, and meters; including the wall penetrations or point of entry (POE) to the interior of the building through the outlet of the meter.

1. The operator is responsible for satisfying all internal safety procedure requirements, training and operator qualification requirements. This procedure and the associated forms do not address such requirements.
2. Use the included *Indoor Atmospheric Corrosion and Leak Assessment Form* (and companion visual comparator) to help guide and record all findings.
3. All reasonable efforts shall be made to survey and inspect visibly accessible service piping.
4. Document any piping that was obstructed and any incomplete portions of the inspection.
5. Leak surveys will be conducted using a conventional portable combustible gas indicator (CGI) with a 0.1% gas reporting threshold. The leak survey is to be conducted by assessing the general atmosphere approximately 6" from the pipe/fitting/meter using an appropriate sample probe. If multiple leaks are found during the leak inspection record only the highest reading.

Several participants will be evaluating a belt clip type combustible gas monitor to assess comparative results from the pipe survey in #5 above vs the general atmosphere while walking and visually assessing the piping /piping components for atmospheric corrosion. If a leak indication is identified with the CGI assessment in #5 and is not detected on the belt clip device or visa-versa, the readings shall be documented on the form. The belt clip general atmosphere devices will have the same detection threshold as the conventional CGI in #5 (0.1% gas detection threshold).

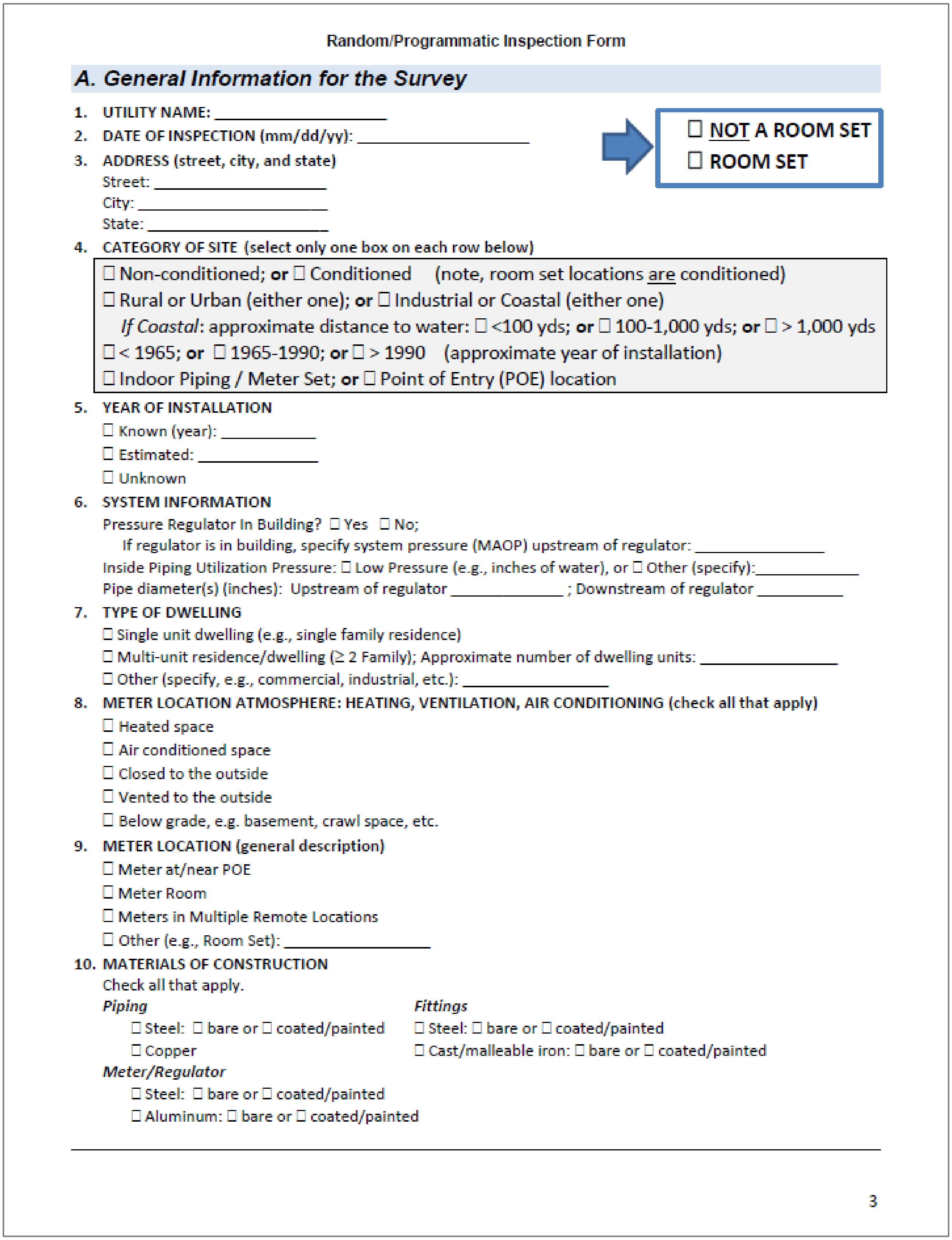
Required Inspection Field Form and Visual Comparator (on next 6 pages)

Section

A. General Information for the Survey
B. Indoor Atmospheric Corrosion Inspection
C. Indoor Leak Measurement Inspection
D. Visual Comparator for use with Indoor Corrosion Inspection[1]

---

[1] The visual comparator is based on SSPC Vis-1 and Vis-3 standards, and discussions between NGA and SSPC may be needed to acquire them for their planned use.



Random/Programmatic Inspection Form

A. General Information for the Survey

☐ NOT A ROOM SET
☐ ROOM SET

1. **UTILITY NAME:** ____________________
2. **DATE OF INSPECTION (mm/dd/yy):** ____________________
3. **ADDRESS (street, city, and state)**
   Street: ____________________
   City: ____________________
   State: ____________________
4. **CATEGORY OF SITE (select only one box on each row below)**

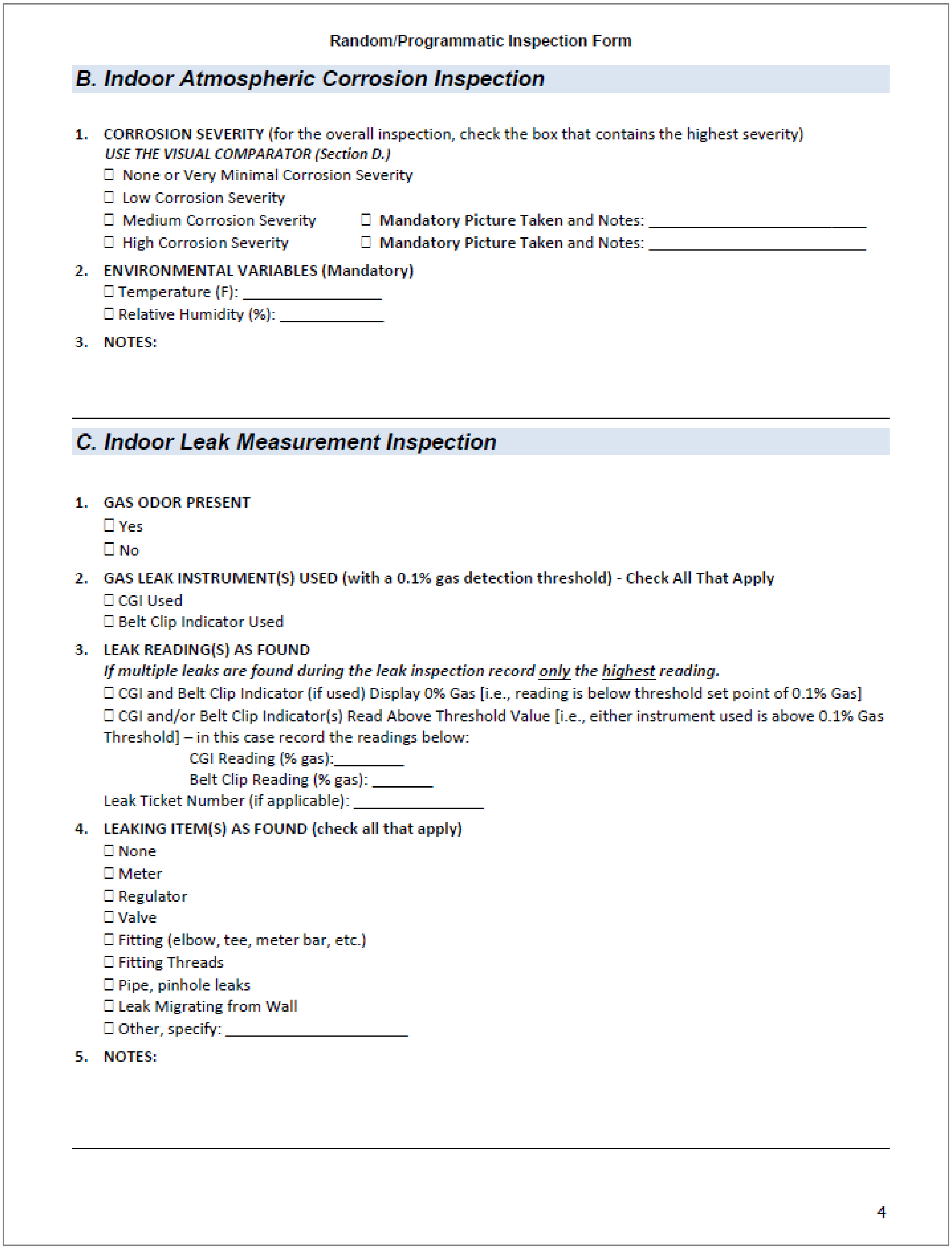
☐ Non-conditioned; **or** ☐ Conditioned (note, room set locations are conditioned)
☐ Rural or Urban (either one); **or** ☐ Industrial or Coastal (either one)
If Coastal: approximate distance to water: ☐ <100 yds; **or** ☐ 100-1,000 yds; **or** ☐ > 1,000 yds
☐ < 1965; **or** ☐ 1965-1990; **or** ☐ > 1990 (approximate year of installation)
☐ Indoor Piping / Meter Set; **or** ☐ Point of Entry (POE) location

5. **YEAR OF INSTALLATION**
   ☐ Known (year): ___________
   ☐ Estimated: ______________
   ☐ Unknown
6. **SYSTEM INFORMATION**
   Pressure Regulator In Building? ☐ Yes ☐ No;
   If regulator is in building, specify system pressure (MAOP) upstream of regulator: _______________
   Inside Piping Utilization Pressure: ☐ Low Pressure (e.g., inches of water), or ☐ Other (specify):____________
   Pipe diameter(s) (inches): Upstream of regulator _____________ ; Downstream of regulator __________
7. **TYPE OF DWELLING**
   ☐ Single unit dwelling (e.g., single family residence)
   ☐ Multi-unit residence/dwelling (≥ 2 Family); Approximate number of dwelling units: ________________
   ☐ Other (specify, e.g., commercial, industrial, etc.): _________________
8. **METER LOCATION ATMOSPHERE: HEATING, VENTILATION, AIR CONDITIONING (check all that apply)**
   ☐ Heated space
   ☐ Air conditioned space
   ☐ Closed to the outside
   ☐ Vented to the outside
   ☐ Below grade, e.g. basement, crawl space, etc.
9. **METER LOCATION (general description)**
   ☐ Meter at/near POE
   ☐ Meter Room
   ☐ Meters in Multiple Remote Locations
   ☐ Other (e.g., Room Set): _________________
10. **MATERIALS OF CONSTRUCTION**
    Check all that apply.

Piping	***Fittings***
☐ Steel: ☐ bare or ☐ coated/painted	☐ Steel: ☐ bare or ☐ coated/painted
☐ Copper	☐ Cast/malleable iron: ☐ bare or ☐ coated/painted

Meter/Regulator
☐ Steel: ☐ bare or ☐ coated/painted
☐ Aluminum: ☐ bare or ☐ coated/painted

3



Random/Programmatic Inspection Form

B. Indoor Atmospheric Corrosion Inspection

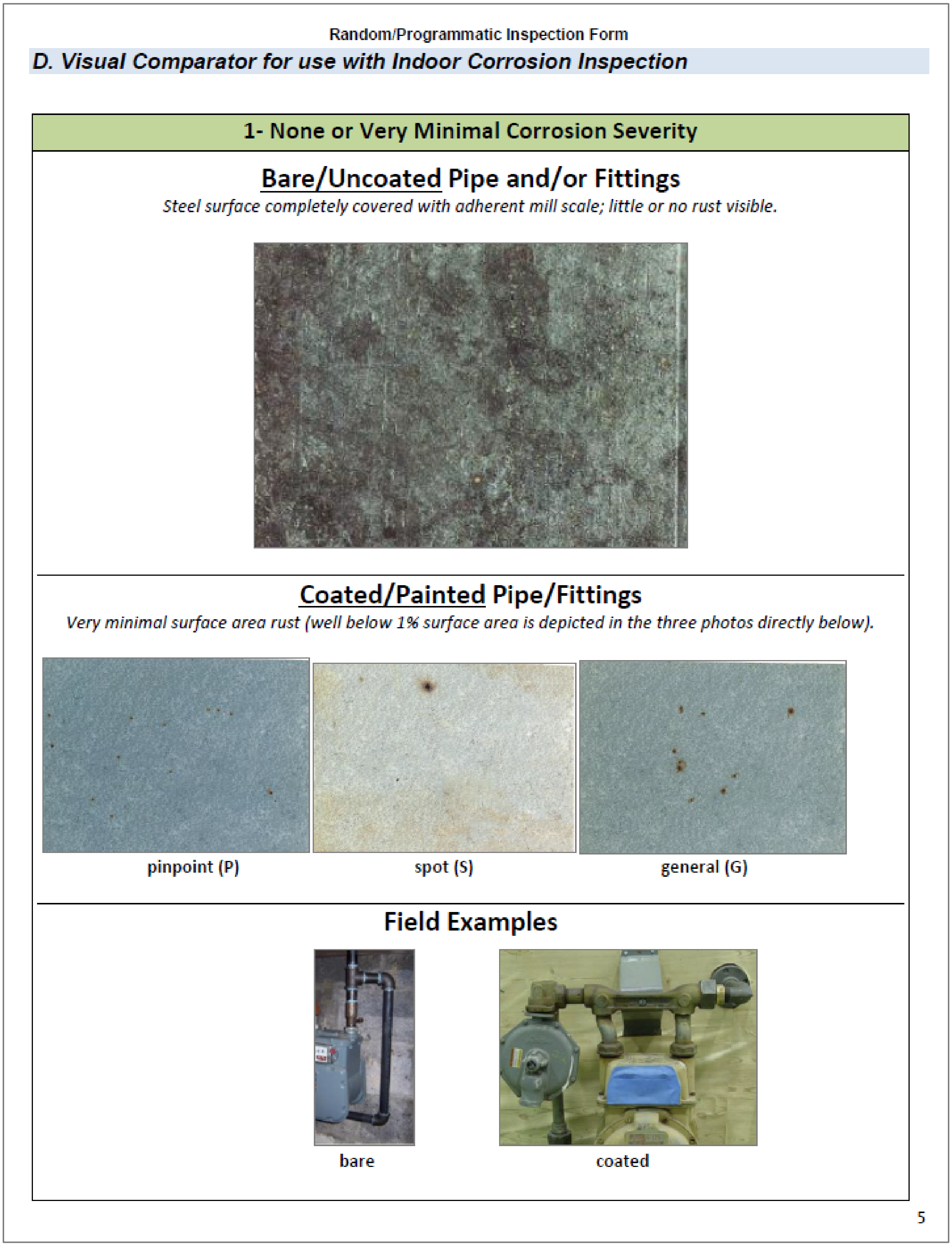
1. **CORROSION SEVERITY** (for the overall inspection, check the box that contains the highest severity)
   USE THE VISUAL COMPARATOR (Section D.)
   - ☐ None or Very Minimal Corrosion Severity
   - ☐ Low Corrosion Severity
   - ☐ Medium Corrosion Severity ☐ **Mandatory Picture Taken and Notes:** ____________________________
   - ☐ High Corrosion Severity ☐ **Mandatory Picture Taken and Notes:** ____________________________
2. **ENVIRONMENTAL VARIABLES (Mandatory)**
   - ☐ Temperature (F): __________________
   - ☐ Relative Humidity (%): _____________
3. **NOTES:**

C. Indoor Leak Measurement Inspection

1. **GAS ODOR PRESENT**
   - ☐ Yes
   - ☐ No
2. **GAS LEAK INSTRUMENT(S) USED (with a 0.1% gas detection threshold) - Check All That Apply**
   - ☐ CGI Used
   - ☐ Belt Clip Indicator Used
3. **LEAK READING(S) AS FOUND**
   If multiple leaks are found during the leak inspection record <u>only</u> the <u>highest</u> reading.
   - ☐ CGI and Belt Clip Indicator (if used) Display 0% Gas [i.e., reading is below threshold set point of 0.1% Gas]
   - ☐ CGI and/or Belt Clip Indicator(s) Read Above Threshold Value [i.e., either instrument used is above 0.1% Gas Threshold] – in this case record the readings below:
     - CGI Reading (% gas):_________
     - Belt Clip Reading (% gas): ________

   Leak Ticket Number (if applicable): _________________
4. **LEAKING ITEM(S) AS FOUND (check all that apply)**
   - ☐ None
   - ☐ Meter
   - ☐ Regulator
   - ☐ Valve
   - ☐ Fitting (elbow, tee, meter bar, etc.)
   - ☐ Fitting Threads
   - ☐ Pipe, pinhole leaks
   - ☐ Leak Migrating from Wall
   - ☐ Other, specify: ________________________
5. **NOTES:**

4



Random/Programmatic Inspection Form

D. Visual Comparator for use with Indoor Corrosion Inspection

1- None or Very Minimal Corrosion Severity

Bare/Uncoated Pipe and/or Fittings

Steel surface completely covered with adherent mill scale; little or no rust visible.

Coated/Painted Pipe/Fittings

Very minimal surface area rust (well below 1% surface area is depicted in the three photos directly below).

pinpoint (P)

spot (S)

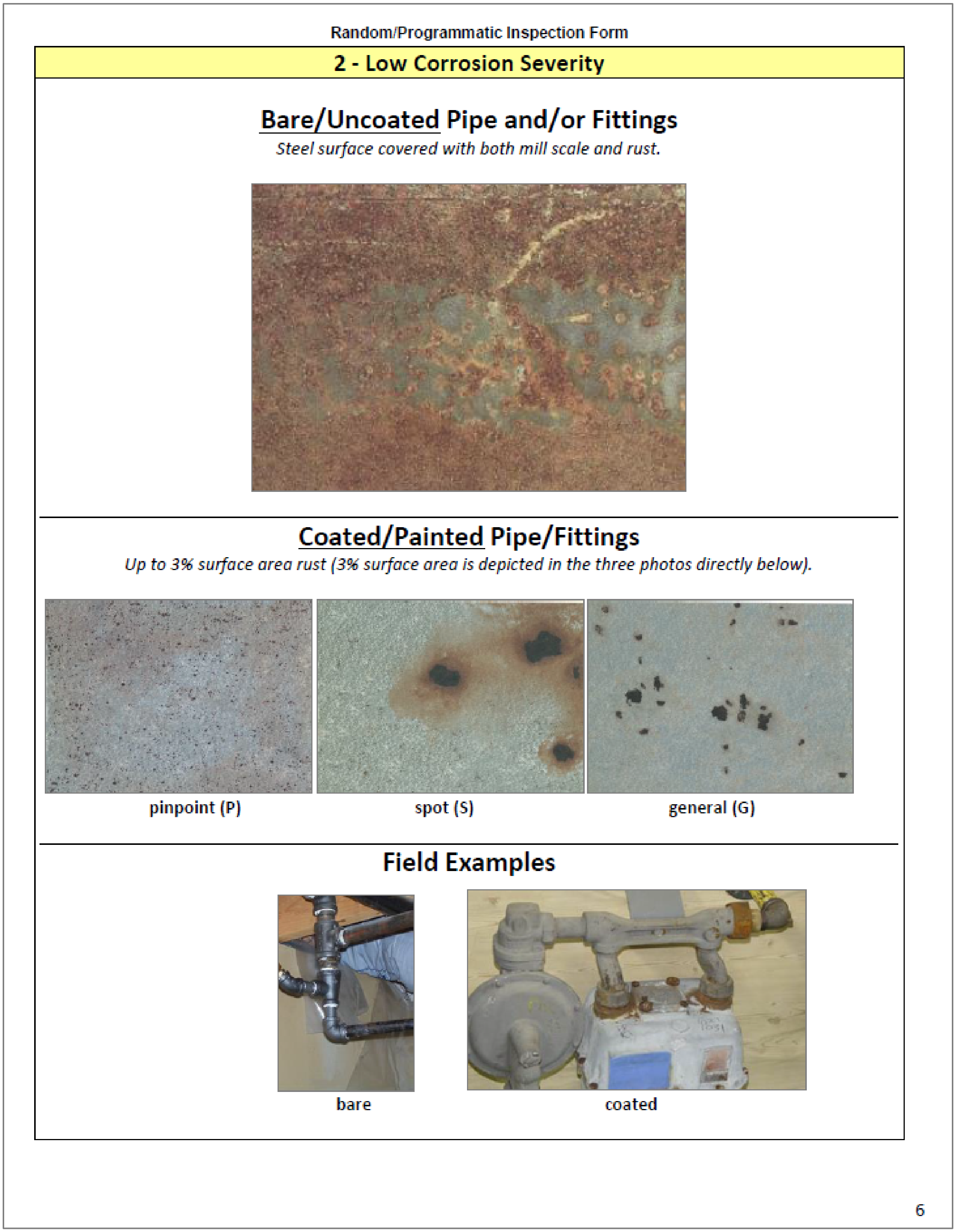
general (G)

Field Examples

bare

coated

5



Random/Programmatic Inspection Form

2 - Low Corrosion Severity

Bare/Uncoated Pipe and/or Fittings

Steel surface covered with both mill scale and rust.

Coated/Painted Pipe/Fittings

Up to 3% surface area rust (3% surface area is depicted in the three photos directly below).

pinpoint (P)

spot (S)

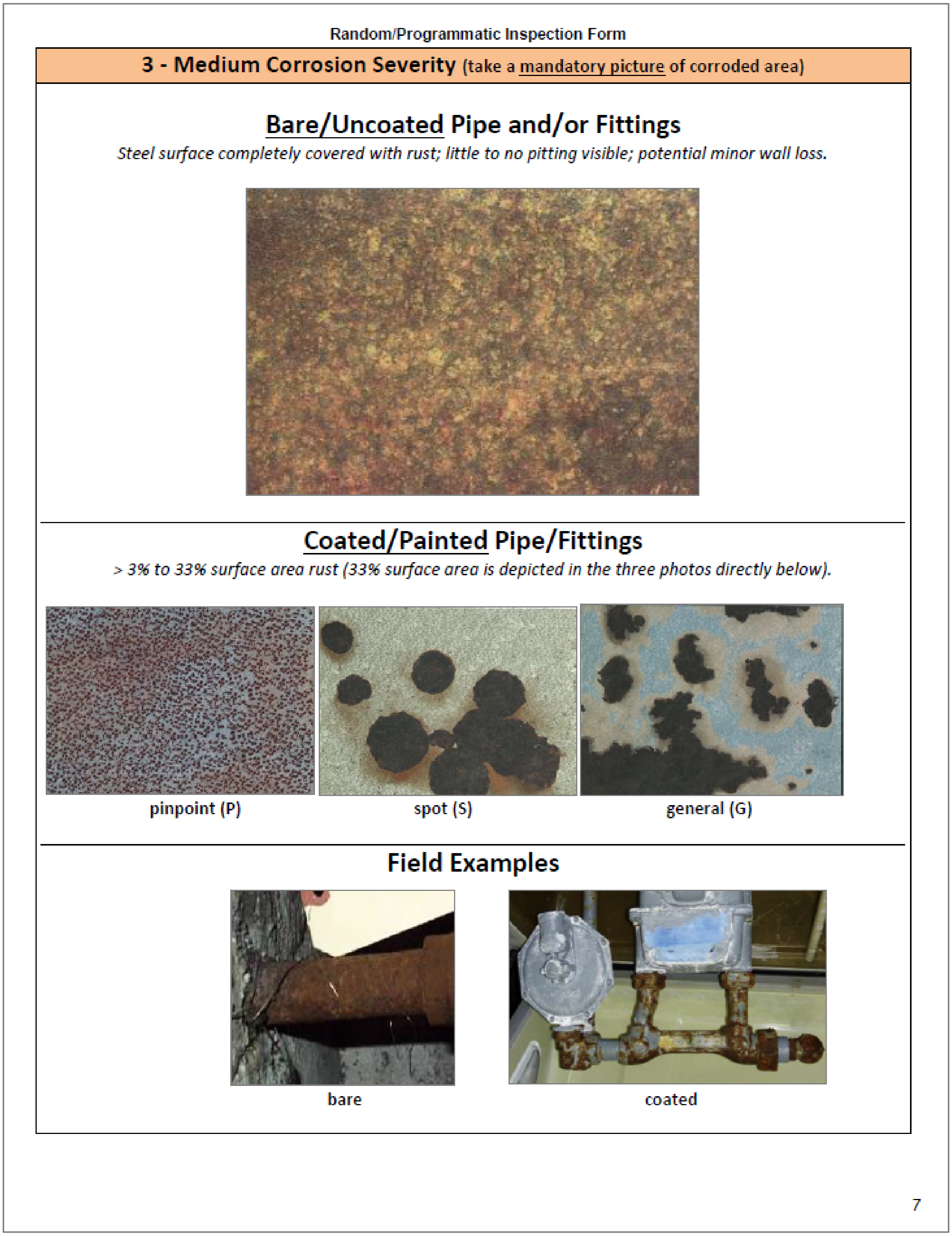
general (G)

Field Examples

bare

coated

6



Random/Programmatic Inspection Form

3 - Medium Corrosion Severity (take a mandatory picture of corroded area)

Bare/Uncoated Pipe and/or Fittings

Steel surface completely covered with rust; little to no pitting visible; potential minor wall loss.

Coated/Painted Pipe/Fittings

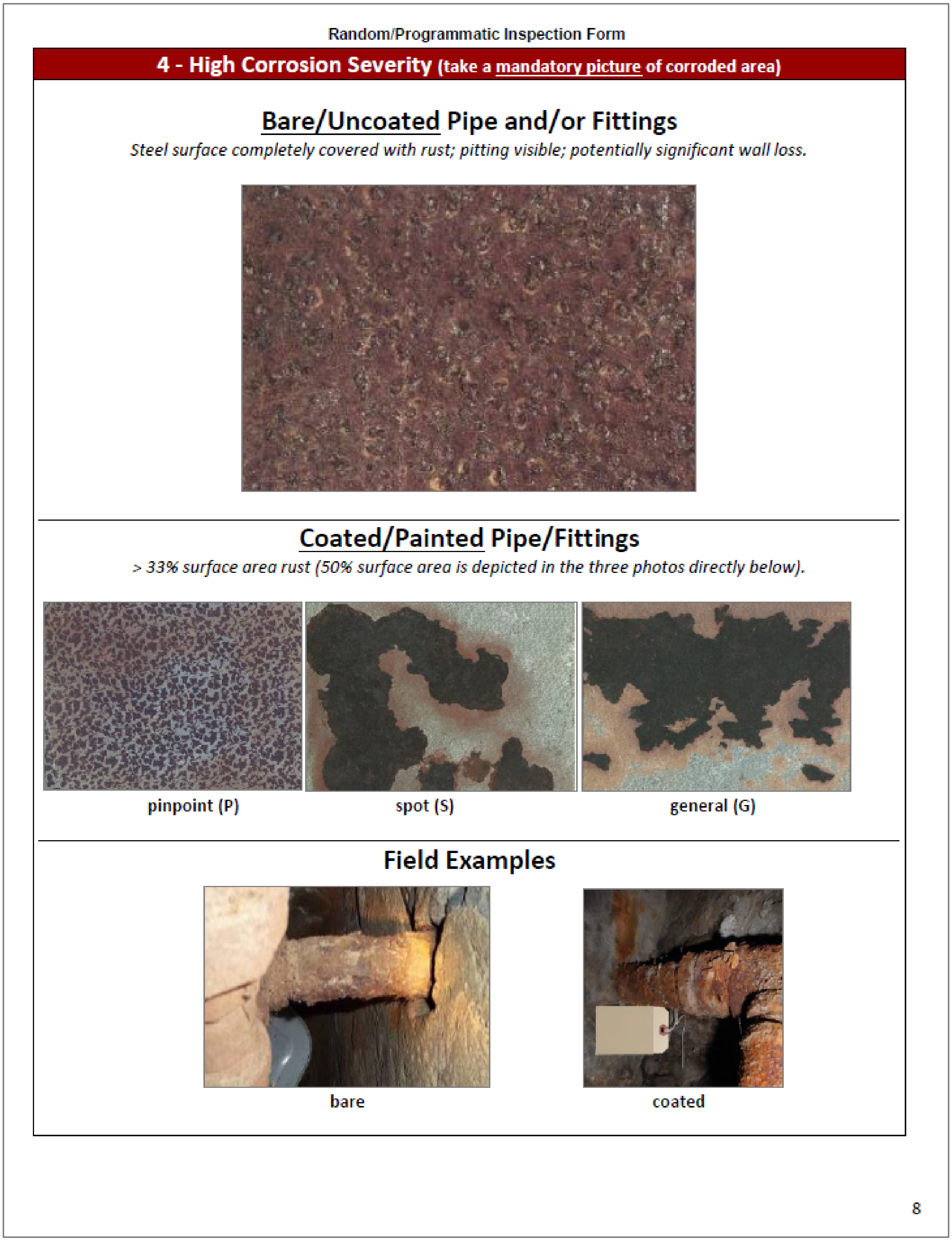
> 3% to 33% surface area rust (33% surface area is depicted in the three photos directly below).

pinpoint (P) spot (S) general (G)

Field Examples

bare coated

7



Random/Programmatic Inspection Form

4 - High Corrosion Severity (take a mandatory picture of corroded area)

Bare/Uncoated Pipe and/or Fittings

Steel surface completely covered with rust; pitting visible; potentially significant wall loss.

Coated/Painted Pipe/Fittings

> 33% surface area rust (50% surface area is depicted in the three photos directly below).

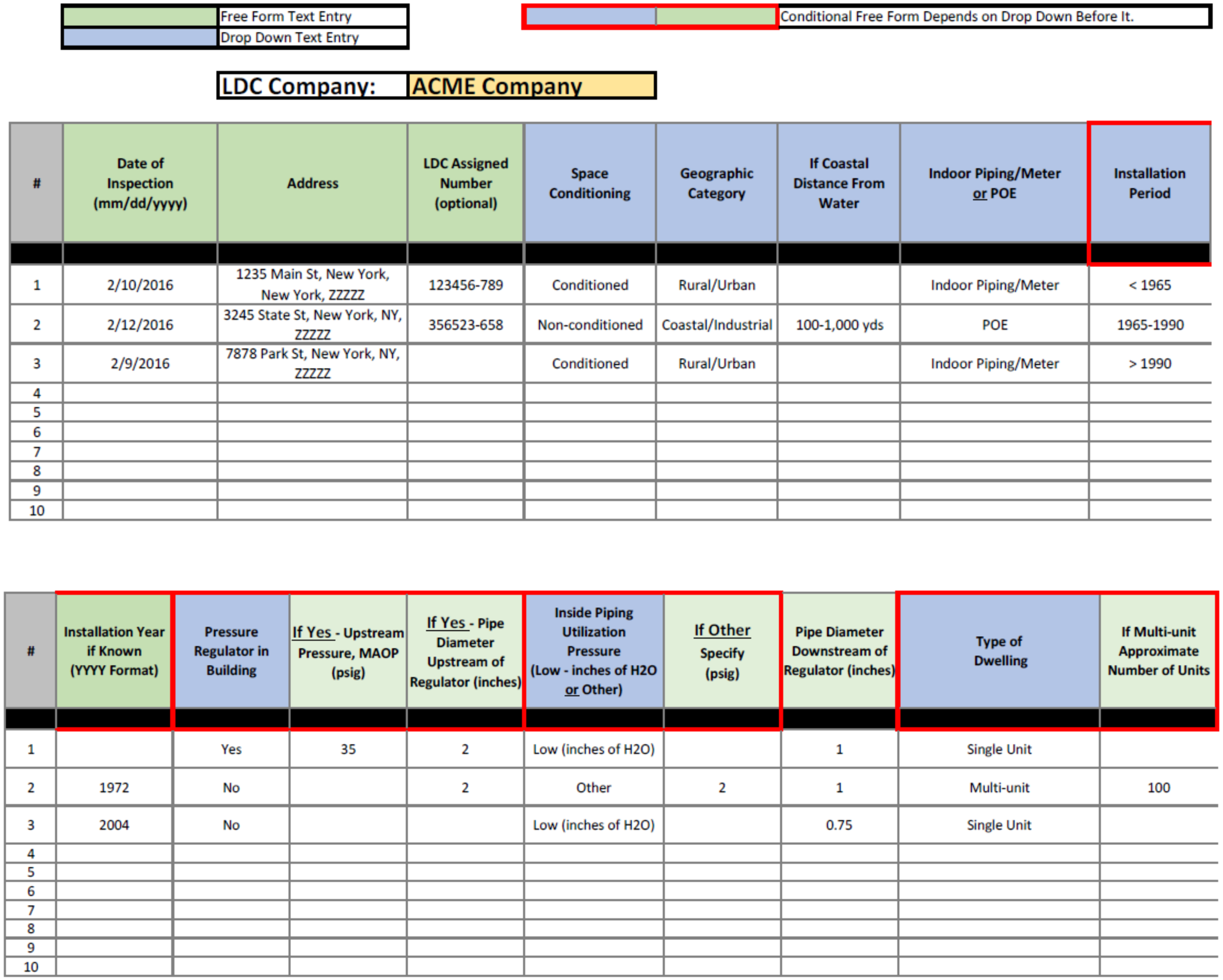
pinpoint (P) spot (S) general (G)

Field Examples

bare coated

8

Spreadsheet Fields Populated from Survey Data



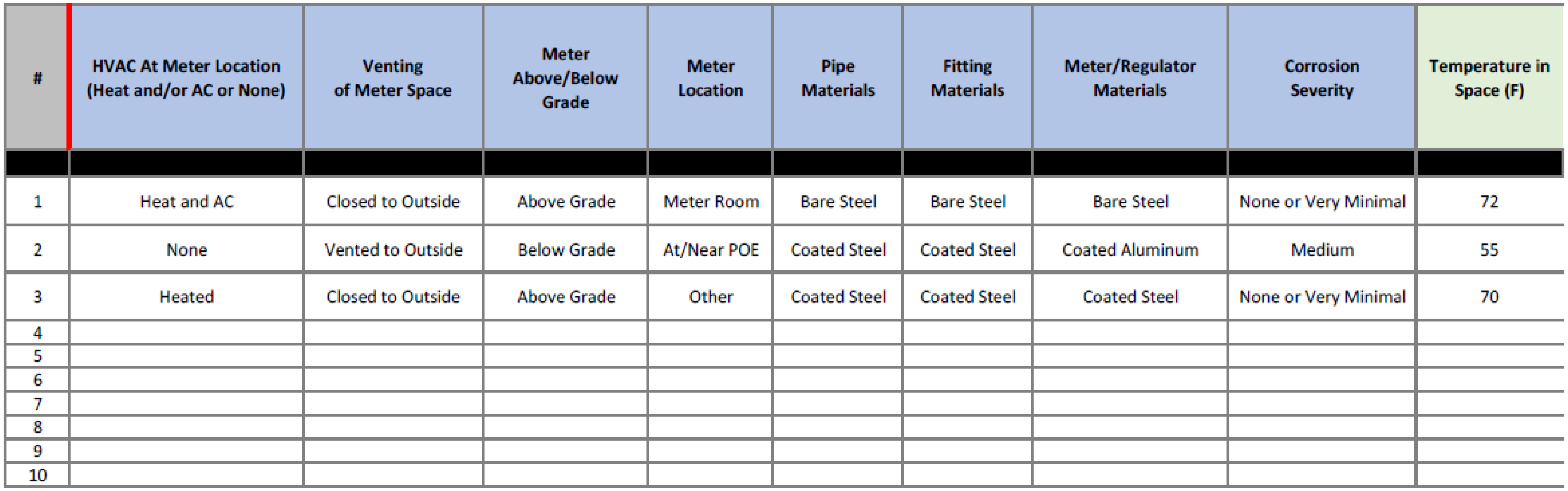
🟩 Free Form Text Entry
🟦 Drop Down Text Entry

🟥 🟦🟩 Conditional Free Form Depends on Drop Down Before It.

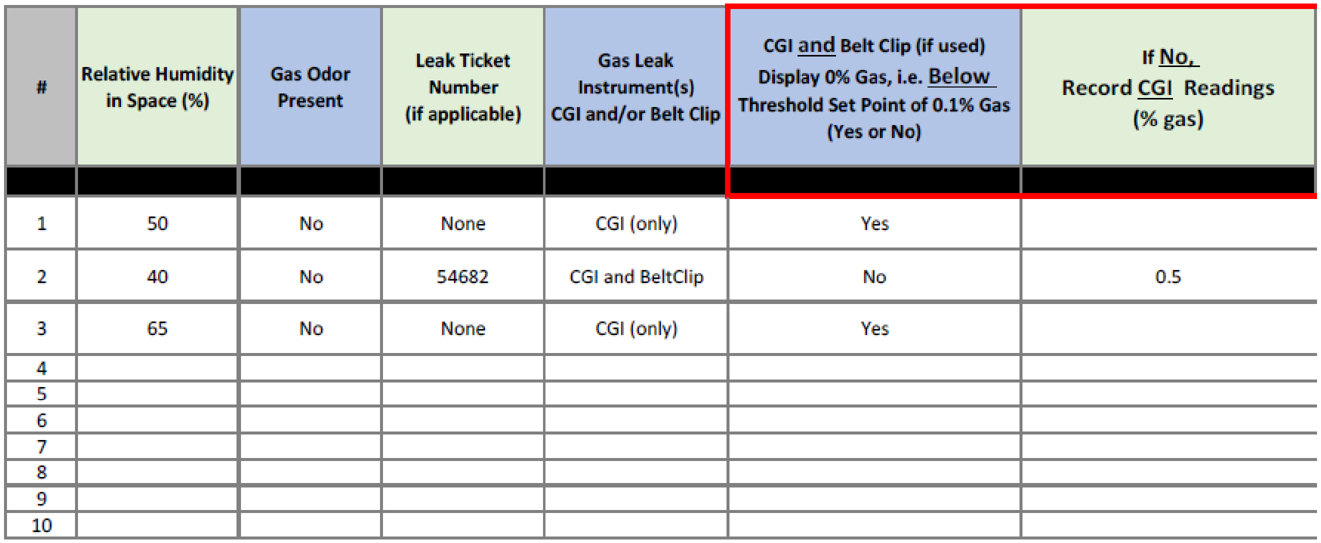
LDC Company: ACME Company

#	Date of Inspection (mm/dd/yyyy)	Address	LDC Assigned Number (optional)	Space Conditioning	Geographic Category	If Coastal Distance From Water	Indoor Piping/Meter or POE	Installation Period
1	2/10/2016	1235 Main St, New York, New York, ZZZZZ	123456-789	Conditioned	Rural/Urban		Indoor Piping/Meter	< 1965
2	2/12/2016	3245 State St, New York, NY, ZZZZZ	356523-658	Non-conditioned	Coastal/Industrial	100-1,000 yds	POE	1965-1990
3	2/9/2016	7878 Park St, New York, NY, ZZZZZ		Conditioned	Rural/Urban		Indoor Piping/Meter	> 1990
4								
5								
6								
7								
8								
9								
10								

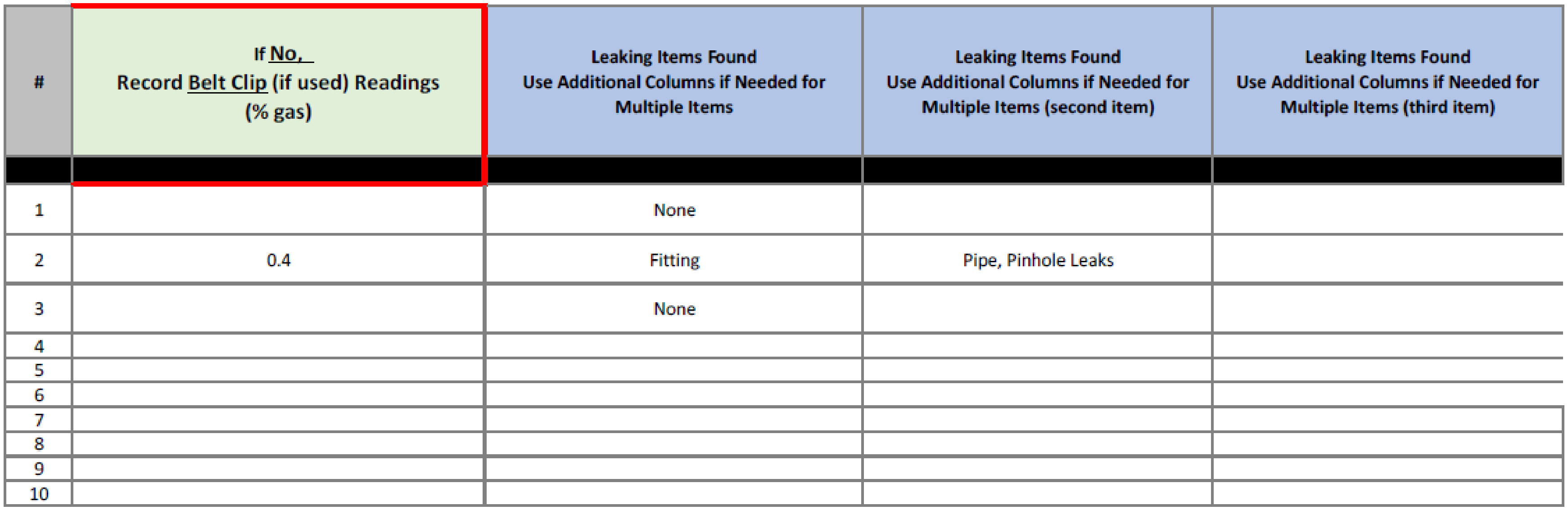
#	Installation Year if Known (YYYY Format)	Pressure Regulator in Building	If Yes - Upstream Pressure, MAOP (psig)	If Yes - Pipe Diameter Upstream of Regulator (inches)	Inside Piping Utilization Pressure (Low - inches of H2O or Other)	If Other Specify (psig)	Pipe Diameter Downstream of Regulator (inches)	Type of Dwelling	If Multi-unit Approximate Number of Units
1		Yes	35	2	Low (inches of H2O)		1	Single Unit	
2	1972	No		2	Other	2	1	Multi-unit	100
3	2004	No			Low (inches of H2O)		0.75	Single Unit	
4									
5									
6									
7									
8									
9									
10									



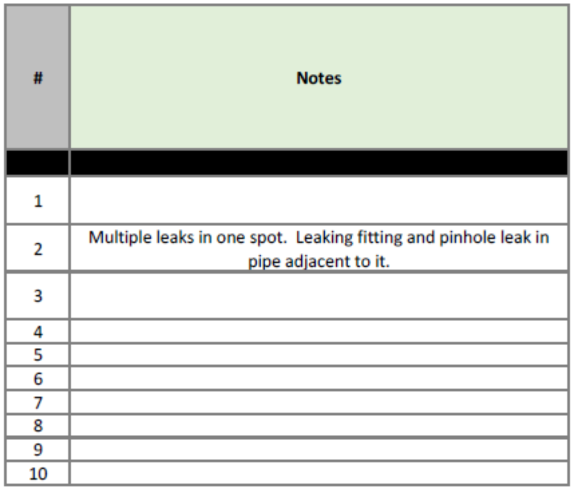
#	HVAC At Meter Location (Heat and/or AC or None)	Venting of Meter Space	Meter Above/Below Grade	Meter Location	Pipe Materials	Fitting Materials	Meter/Regulator Materials	Corrosion Severity	Temperature in Space (F)
1	Heat and AC	Closed to Outside	Above Grade	Meter Room	Bare Steel	Bare Steel	Bare Steel	None or Very Minimal	72
2	None	Vented to Outside	Below Grade	At/Near POE	Coated Steel	Coated Steel	Coated Aluminum	Medium	55
3	Heated	Closed to Outside	Above Grade	Other	Coated Steel	Coated Steel	Coated Steel	None or Very Minimal	70
4									
5									
6									
7									
8									
9									
10									



#	Relative Humidity in Space (%)	Gas Odor Present	Leak Ticket Number (if applicable)	Gas Leak Instrument(s) CGI and/or Belt Clip	CGI and Belt Clip (if used) Display 0% Gas, i.e. Below Threshold Set Point of 0.1% Gas (Yes or No)	If No, Record CGI Readings (% gas)
1	50	No	None	CGI (only)	Yes	
2	40	No	54682	CGI and BeltClip	No	0.5
3	65	No	None	CGI (only)	Yes	
4						
5						
6						
7						
8						
9						
10						

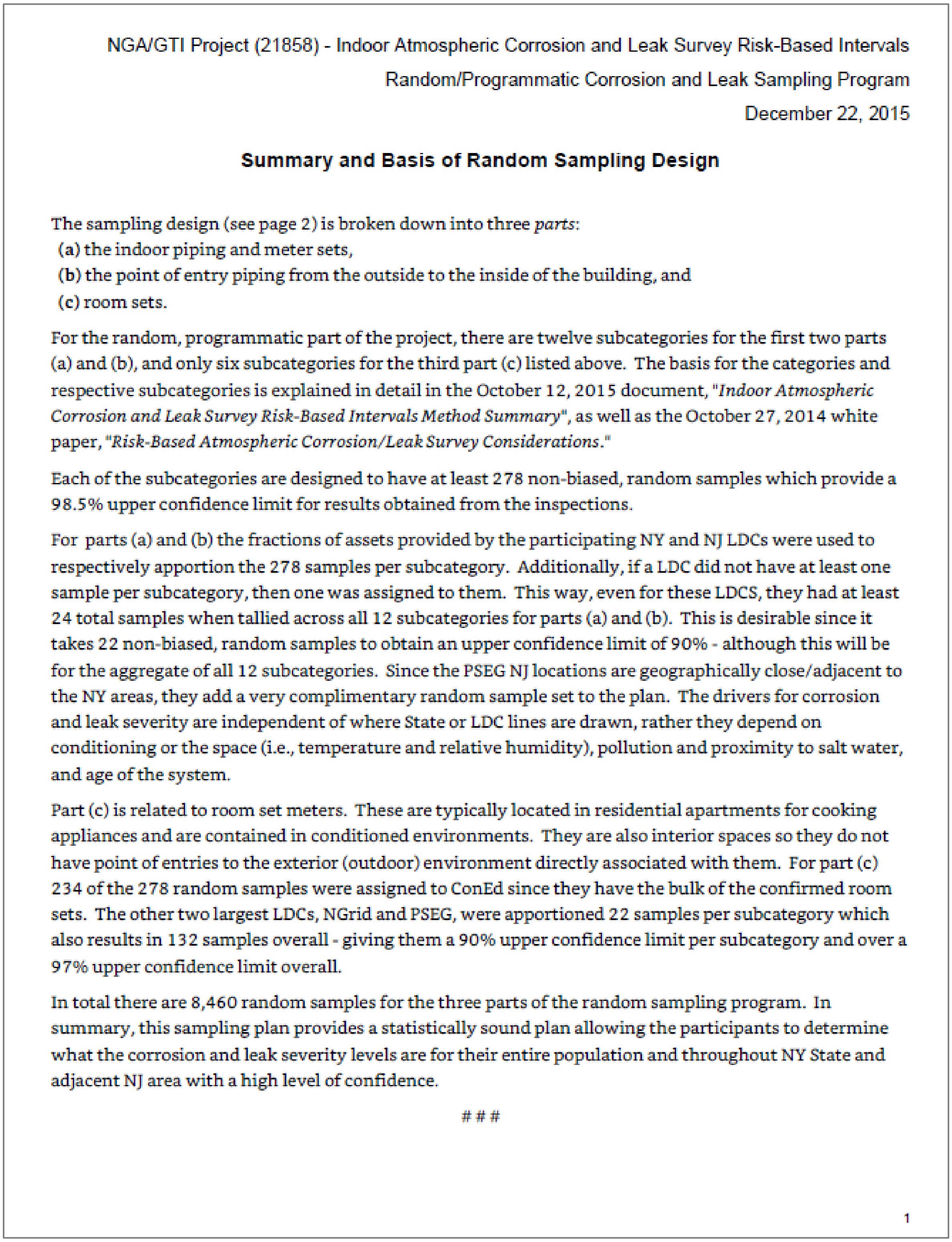


#	If No, Record Belt Clip (if used) Readings (% gas)	Leaking Items Found Use Additional Columns if Needed for Multiple Items	Leaking Items Found Use Additional Columns if Needed for Multiple Items (second item)	Leaking Items Found Use Additional Columns if Needed for Multiple Items (third item)
1		None		
2	0.4	Fitting	Pipe, Pinhole Leaks	
3		None		
4				
5				
6				
7				
8				
9				
10				



#	Notes
1	
2	Multiple leaks in one spot. Leaking fitting and pinhole leak in pipe adjacent to it.
3	
4	
5	
6	
7	
8	
9	
10	

11 Appendix D – Summary and Basis of Random Sampling Experimental Design



December 22, 2015

Summary and Basis of Random Sampling Design

The sampling design (see page 2) is broken down into three *parts*:
(a) the indoor piping and meter sets,
(b) the point of entry piping from the outside to the inside of the building, and
(c) room sets.

For the random, programmatic part of the project, there are twelve subcategories for the first two parts (a) and (b), and only six subcategories for the third part (c) listed above. The basis for the categories and respective subcategories is explained in detail in the October 12, 2015 document, "*Indoor Atmospheric Corrosion and Leak Survey Risk-Based Intervals Method Summary*", as well as the October 27, 2014 white paper, "*Risk-Based Atmospheric Corrosion/Leak Survey Considerations.*"

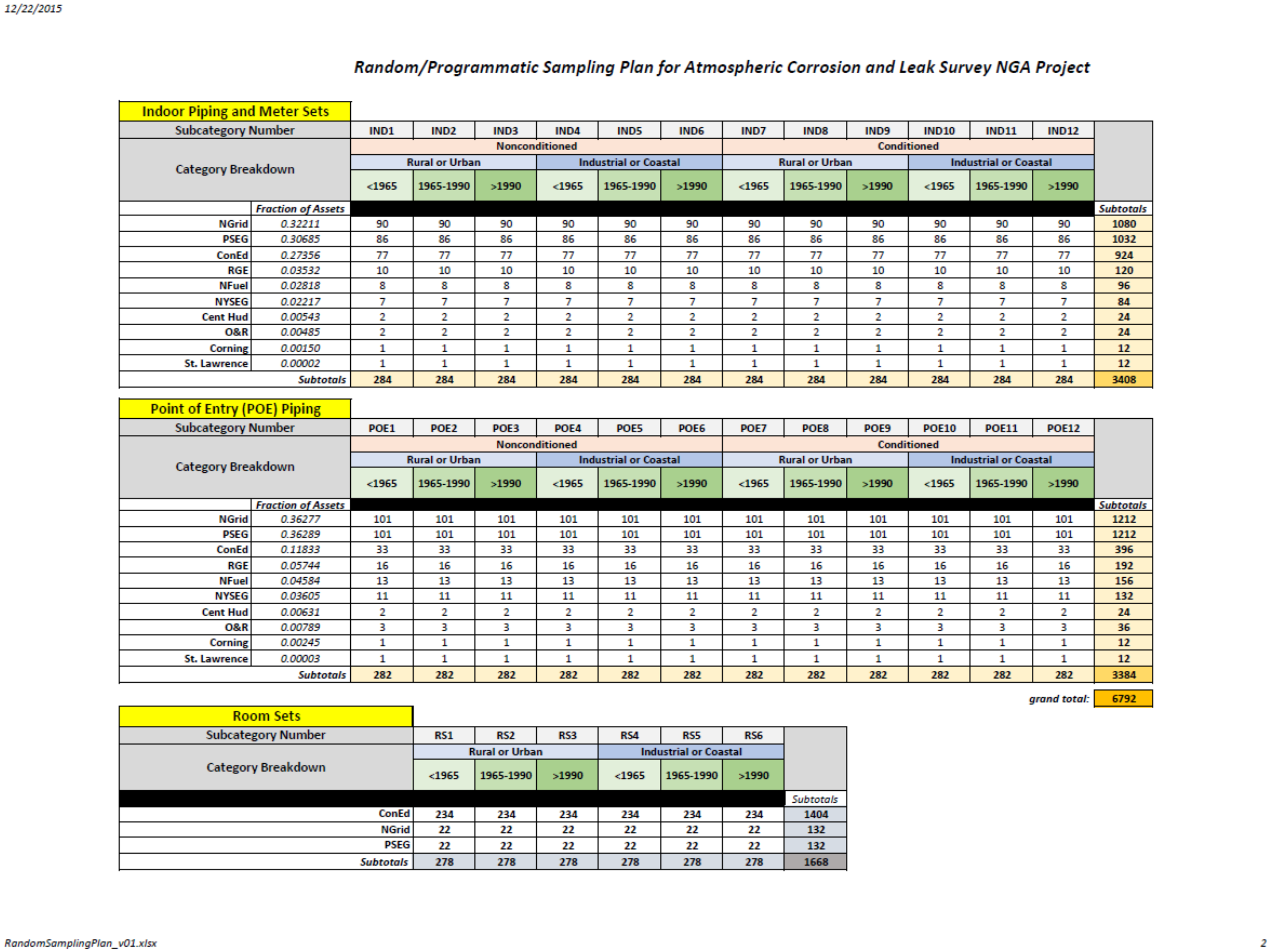
Each of the subcategories are designed to have at least 278 non-biased, random samples which provide a 98.5% upper confidence limit for results obtained from the inspections.

For parts (a) and (b) the fractions of assets provided by the participating NY and NJ LDCs were used to respectively apportion the 278 samples per subcategory. Additionally, if a LDC did not have at least one sample per subcategory, then one was assigned to them. This way, even for these LDCS, they had at least 24 total samples when tallied across all 12 subcategories for parts (a) and (b). This is desirable since it takes 22 non-biased, random samples to obtain an upper confidence limit of 90% - although this will be for the aggregate of all 12 subcategories. Since the PSEG NJ locations are geographically close/adjacent to the NY areas, they add a very complimentary random sample set to the plan. The drivers for corrosion and leak severity are independent of where State or LDC lines are drawn, rather they depend on conditioning or the space (i.e., temperature and relative humidity), pollution and proximity to salt water, and age of the system.

Part (c) is related to room set meters. These are typically located in residential apartments for cooking appliances and are contained in conditioned environments. They are also interior spaces so they do not have point of entries to the exterior (outdoor) environment directly associated with them. For part (c) 234 of the 278 random samples were assigned to ConEd since they have the bulk of the confirmed room sets. The other two largest LDCs, NGrid and PSEG, were apportioned 22 samples per subcategory which also results in 132 samples overall - giving them a 90% upper confidence limit per subcategory and over a 97% upper confidence limit overall.

In total there are 8,460 random samples for the three parts of the random sampling program. In summary, this sampling plan provides a statistically sound plan allowing the participants to determine what the corrosion and leak severity levels are for their entire population and throughout NY State and adjacent NJ area with a high level of confidence.

# # #



12/22/2015

Random/Programmatic Sampling Plan for Atmospheric Corrosion and Leak Survey NGA Project

Indoor Piping and Meter Sets

Subcategory Number		IND1	IND2	IND3	IND4	IND5	IND6	IND7	IND8	IND9	IND10	IND11	IND12	
Category Breakdown		Nonconditioned						Conditioned						
		Rural or Urban			Industrial or Coastal			Rural or Urban			Industrial or Coastal			
		<1965	1965-1990	>1990	<1965	1965-1990	>1990	<1965	1965-1990	>1990	<1965	1965-1990	>1990	
	Fraction of Assets													*Subtotals*
NGrid	0.32211	90	90	90	90	90	90	90	90	90	90	90	90	1080
PSEG	0.30685	86	86	86	86	86	86	86	86	86	86	86	86	1032
ConEd	0.27356	77	77	77	77	77	77	77	77	77	77	77	77	924
RGE	0.03532	10	10	10	10	10	10	10	10	10	10	10	10	120
NFuel	0.02818	8	8	8	8	8	8	8	8	8	8	8	8	96
NYSEG	0.02217	7	7	7	7	7	7	7	7	7	7	7	7	84
Cent Hud	0.00543	2	2	2	2	2	2	2	2	2	2	2	2	24
O&R	0.00485	2	2	2	2	2	2	2	2	2	2	2	2	24
Corning	0.00150	1	1	1	1	1	1	1	1	1	1	1	1	12
St. Lawrence	0.00002	1	1	1	1	1	1	1	1	1	1	1	1	12
	Subtotals	284	284	284	284	284	284	284	284	284	284	284	284	3408

Point of Entry (POE) Piping

Subcategory Number		POE1	POE2	POE3	POE4	POE5	POE6	POE7	POE8	POE9	POE10	POE11	POE12	
Category Breakdown		Nonconditioned						Conditioned						
		Rural or Urban			Industrial or Coastal			Rural or Urban			Industrial or Coastal			
		<1965	1965-1990	>1990	<1965	1965-1990	>1990	<1965	1965-1990	>1990	<1965	1965-1990	>1990	
	Fraction of Assets													*Subtotals*
NGrid	0.36277	101	101	101	101	101	101	101	101	101	101	101	101	1212
PSEG	0.36289	101	101	101	101	101	101	101	101	101	101	101	101	1212
ConEd	0.11833	33	33	33	33	33	33	33	33	33	33	33	33	396
RGE	0.05744	16	16	16	16	16	16	16	16	16	16	16	16	192
NFuel	0.04584	13	13	13	13	13	13	13	13	13	13	13	13	156
NYSEG	0.03605	11	11	11	11	11	11	11	11	11	11	11	11	132
Cent Hud	0.00631	2	2	2	2	2	2	2	2	2	2	2	2	24
O&R	0.00789	3	3	3	3	3	3	3	3	3	3	3	3	36
Corning	0.00245	1	1	1	1	1	1	1	1	1	1	1	1	12
St. Lawrence	0.00003	1	1	1	1	1	1	1	1	1	1	1	1	12
	Subtotals	282	282	282	282	282	282	282	282	282	282	282	282	3384

grand total: 6792

Room Sets

Subcategory Number	RS1	RS2	RS3	RS4	RS5	RS6	
Category Breakdown	Rural or Urban			Industrial or Coastal			
	<1965	1965-1990	>1990	<1965	1965-1990	>1990	
							Subtotals
ConEd	234	234	234	234	234	234	1404
NGrid	22	22	22	22	22	22	132
PSEG	22	22	22	22	22	22	132
Subtotals	278	278	278	278	278	278	1668

RandomSamplingPlan_v01.xlsx

2

12 Appendix E - CGI vs. Belt Clip Error Type Comparison

A separate statistical analysis of the traditional handheld CGI vs. Belt Clip CGI instruments is presented below. The fundamental difference between the two instruments is in the sampling technique. The handheld unit utilized a sample probe that allowed sampling in relatively close proximity to the pipe being surveyed where the belt clip instrument sampled the general atmosphere in the vicinity of the technician conducting the visual survey. There were 221 leaks above and below 0.1% Gas where both the CGI and a Belt Clip detector were used and recorded. This allows for a standard 4-part error analysis to be done. The CGI is taken as the referee or actual % Gas level and the Belt Clip detector is compared to the CGI value. Then the likelihood of true/false negative/positives are calculated using conditional probability.

12.1 Scatter Plot of CGI vs. Belt Clip CGI Readings

The scatter plot of the CGI vs. the Belt Clip CGI readings is shown in Figure 78 below. The dashed black line is the unity line plot of 1:1 correspondence.

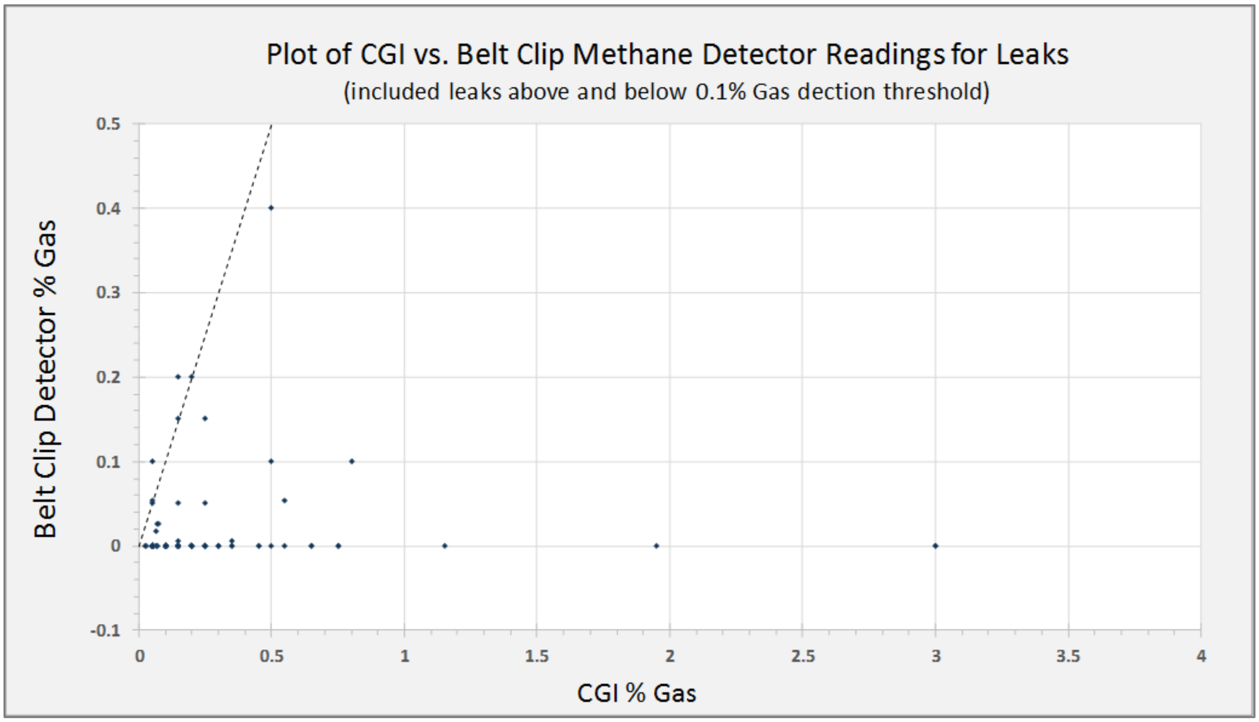


Figure 78. Scatter Plot of Belt Clip CGI vs. Handheld CGI % Gas Readings for Observed Leaks at the 0.1%Gas Threshold

12.2 Analysis of Readings Above and Below 0.1% Gas for Leaks

The readings above, equal to, and below 0.1% Gas were compared between the CGI and Belt Clip instruments and the Error types for the Belt Clip Detector are shown in Table 26 below. The errors with confidence limits are shown in Figure 79.

Table 26. Belt Clip Compared to CGI (at 0.1% Gas)

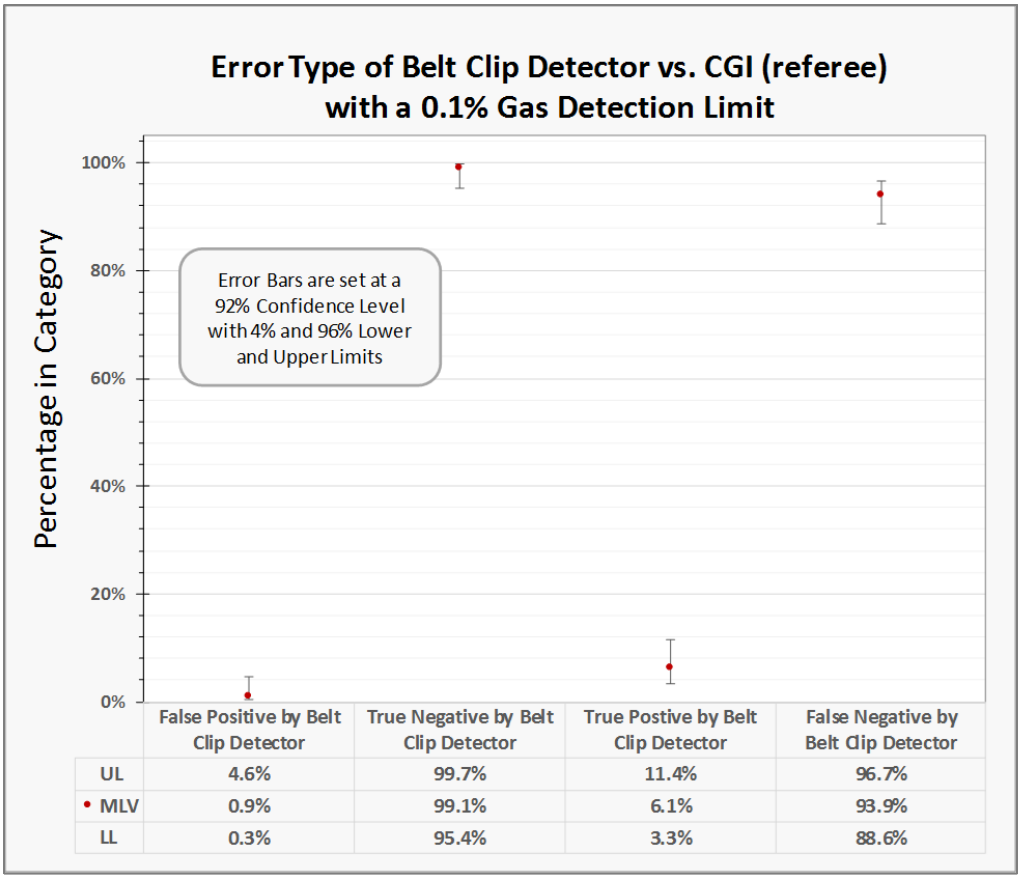
For 106 actual levels of < 0.1% Gas	
1 false positive	105 true negative
For 115 actual levels >= 0.1% Gas	
7 true positives	108 false negatives

	POSITIVE	*NEGATIVE*	Sub-totals	Total
TRUE	7	105	112	221
FALSE	1	108	109	
Sub-totals	8	213		
Total	221			

Notes:

- There are 221 leaking readings (above and below 0.1% Gas) where both instruments were used
- Negative: < 0.1% Gas
- Positive: >= 0.1% Gas

12.3 Predicted Errors by Type for the Broader Population of Leaks - Belt Clip Detector



Error Type of Belt Clip Detector vs. CGI (referee) with a 0.1% Gas Detection Limit

Error Bars are set at a 92% Confidence Level with 4% and 96% Lower and Upper Limits

	False Positive by Belt Clip Detector	True Negative by Belt Clip Detector	True Postive by Belt Clip Detector	False Negative by Belt Clip Detector
UL	4.6%	99.7%	11.4%	96.7%
• MLV	0.9%	99.1%	6.1%	93.9%
LL	0.3%	95.4%	3.3%	88.6%

Figure 79. Predicted Error Type for the Population for the Belt Clip Detector at 0.1% Gas Threshold

13 Attachments and Addendum

Attachment 1 - White Paper Risk-Based Atmospheric Corrosion / Leak Survey Considerations.

October 27, 2014, Operations Technology Development (OTD), GTI Report No. 21678 Phase 1, 71 pages.

Attachment 2 - Leak Survey Equipment Considerations for NY Operations - Development of a Regulatory Conformance and Technology Applicability White Paper.

May 12, 2016, Northeast Gas Association (NGA), GTI Report No. 21971, 27 pages.

Addendum - Indoor Atmospheric Corrosion and Leak Survey Risk-Based Intervals Opportunistic Sample Analysis - Addendum Report

the Energy to Lead

GTI White Paper No. 21678

WHITE PAPER

Risk-Based Atmospheric Corrosion / Leak Survey Considerations

Report Issued
October 27, 2014

Prepared For
Operations Technology Development (OTD), NFP

Project Investors
National Grid
Consolidated Edison
National Fuel Gas
New York State Electric & Gas / RG&E

Technical Contact
Mr. Daniel Ersoy
M.Sc., NACE CIP III, CF.APMP
R&D Executive Director, GTI
847.768.0663
daniel.ersoy@gastechnology.org

Project Team
Daniel Ersoy, M.Sc., NACE CIP III, CF.APMP
Khalid Farrag, PhD, P.E., PMP
Carol Worster
Mike Mensinger, Jr.

Gas Technology Institute
1700 S. Mount Prospect Rd.
Des Plaines, Illinois 60018
www.gastechnology.org

Business Contact
Paul Armstrong
Dir. of Bus. Development, GTI
781.449.1141
paul.armstrong@gastechnology.org

Signature Page

		Date
AUTHOR		
Daniel A. Ersoy	Daniel Ersoy//S//	October 27, 2014
	Title: R&D Executive Director & Sr. Inst. Metallurgist/Corrosion Eng.	
CO-AUTHOR		
Khalid Farrag	Khalid Farrag//S//	October 27, 2014
	Title: Senior Institute Engineer	
REVIEWED BY		
Andrew Hammerschmidt	Andrew Hammerschmidt//S//	October 27, 2014
	Title: Director of Project Management	

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Executive Summary

Background

This white paper was performed at the request of Operations Technology Development (OTD), NFP, who engaged the Gas Technology Institute to review historical and current data on indoor service piping.

The paper starts by presenting the fundamental principles of indoor and outdoor atmospheric corrosion. The paper also provides a detailed review of the published, peer-reviewed literature related to field data on indoor corrosion, and compares and contrasts this to outdoor corrosion for iron and steel piping materials.

In addition, thousands of recent inspections in NY and New England States completed on outdoor and indoor services by operators were collected and statistically analyzed to determine the trends and drivers behind the observed corrosion rates. A similar analysis was completed on exclusively indoor leak survey data from LDC operators.

Finally, all the findings were summarized and related to risk-based considerations for setting appropriate inspection intervals for indoor service piping.

Peer-Reviewed Literature, Corrosion Theory, and Detailed Field Testing

The peer-reviewed literature search concluded that relative humidity, and its interaction with atmospheric constituents, are the main drivers for atmospheric corrosion. The variation in humidity and temperature are dramatically lower indoors than outdoors and when combined with the absolute lower humidity and pollutant levels, it results in lower corrosion rates for indoor steel and iron assets.

The scientific/engineering data showed that indoor atmospheres result in an often significantly low corrosion rate than for outdoor atmospheres. Mean indoor corrosion rates are reported at 2-3 orders of magnitude (100 to 1,000 times) lower than outdoor rates. A seminal, multi-year indoor vs. outdoor corrosion rate study showed indoor corrosion of steel/iron to be a factor of 2,000 times lower than the outdoor corrosion rates. This study included New York, New Jersey, Los Angeles, Chicago, Texas, Indiana, and South Carolina. The published work collected concluded that the marked reduction in indoor iron corrosion is accounted for by both a reduction in high humidity occurrences and a reduction in pollutant levels.

A practical example of pipe corrosion using the very conservative 99% upper confidence levels for corrosion rates, showed that it would take about 100 times longer to corrode through 25% of a ¾ inch diameter iron pipe wall indoors as it would outdoors. It also shows that the buried conditions would corrode the same distance in about half the time of outdoor. It is evident that different, extended inspection intervals are warranted and appropriate for indoor environments vs. outdoor environments.

Recent New York Operator Outdoor and Indoor Corrosion and Leak Survey Data Findings

Historical (2007-2008) NY LDC corrosion and leak surveys (outside and indoor) of meter-set populations were collected and analyzed. A statistical regression analysis concluded that the most significant parameter related to corrosion condition was relative humidity, just as the peer-reviewed literature concluded.

Pipe age had the next highest correlation. The number of indoor locations with pitting corrosion was very small. For example, in New England and Long Island, an average of 1% of the indoor inspections had corrosion conditions that required further action; the percentage in New York City was even lower at 0.18%.

Supplementing this was a second set of data, recently completed in September of 2014, of four NY State LDCs with over 1,000 on site, indoor corrosion and meter set/piping surveys. The results also showed that approximately 98% of the inspections had no corrosion or mild surface rust that was cleaned with a brush. Only 1% of the corrosion required repair or replacement, and the operators have a very conservative position in these cases.

New York Operator Outdoor and Indoor Leak Survey Data and Analysis Findings

The indoor leak records in NY State show that about 5% of the records had minor to medium indications from the soap bubble tests. About 0.1% of these records had a higher leak indication. Leaks were mostly identified from emergency odor calls (72%); this is in contrast to the corrosion indications which were mostly identified as a consequence of gaining access while on-site for other routine inspection work (80%).

The effect of pipe age, humidity, meter locations, and pipe material type were investigated on leak records. None of these parameters were identified as variables affecting leak records. Leak records did not correlate to corrosion indications. Most of the leaks were in the pipe and threaded connections. A small percentage (2%) was at the meter and regulator piping system.

The leak records were implemented in a conditional probability approach to estimate the likelihood of leaks due to site conditions. Decision tree diagrams were plotted to illustrate the procedure. These probabilities can be used to rank the risk associated with the occurrence of leaks.

Conclusions

Based on decades of peer-reviewed field testing and analysis, coupled with 2007, 2008, and 2014 in-field surveys by NY State operators of thousands of service sets, the indoor corrosion rate is typically 100-1,000's of time lower than the outdoor rates. Furthermore, the occurrence of noteworthy indoor atmospheric corrosion is encountered less than 1% of the time, sometimes significantly less than 1%.

The combined findings of this paper suggest that the intervals for indoor corrosion surveys can defensibly be set to longer periodicities as compared to outdoor surveys of similar meter sets and piping. This would facilitate focused optimization of available Operator resources on other, more aggressive environments, thereby lowering composite risk and increasing overall safety; all principles of distribution integrity management.

Risk-Based Considerations for Survey Intervals

A set of risk-based considerations for categorizing the indoor atmospheric service and indoor leak survey environments, to assist with the development of engineering based indoor corrosion and leak survey intervals, are presented in the final section of the white paper.

Categorical Approach to Appropriately Set and Refine Indoor Corrosion Survey Intervals

An approach that leverages the very conservative 99% upper confidence corrosion rate, could allow operators to set the typical intervals for indoor atmospheric corrosion surveys to 15-20 years. Based on the information presented in this paper and the cited references, this would be quite conservative, with corrosion of less than 2% of the pipe wall, which is quite low from an engineering design basis.

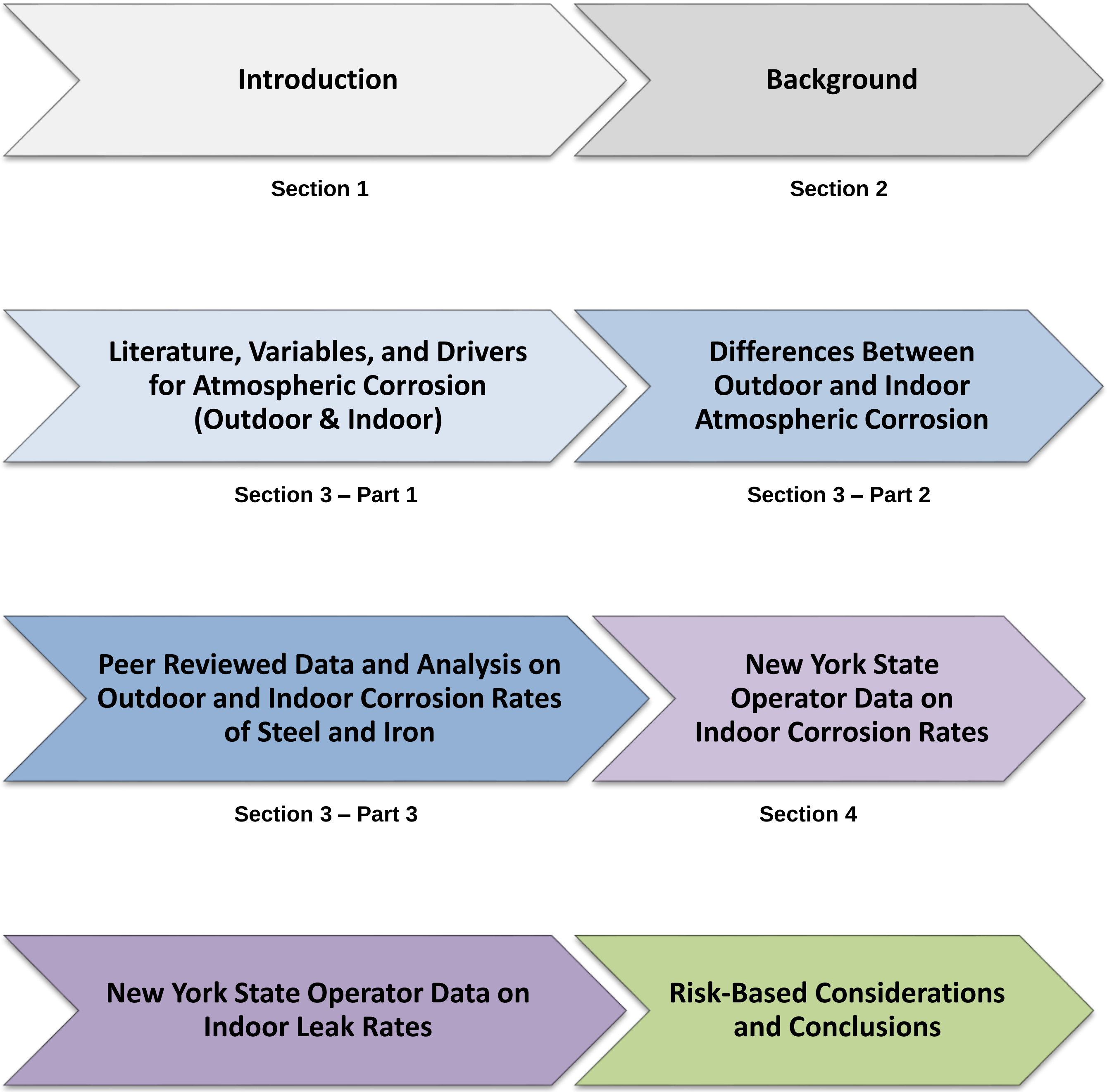
As atmospheres are noted to be more benign than the 99% upper confidence level, then these system components could be put into categories with longer times between intervals, say 20-25 years, or others as appropriate. Likewise, as atmospheres or environments are noted to more corrosive, the system components could be shifted to a shorter interval between surveys, say 10-15 years.

The risk-based considerations presented at the end of the paper should be leveraged with ongoing, continuous feedback from surveys. The operator should incorporate ongoing data collection and feedback to refine the inspection interval categories, their length, and what components go into each category.

The content of this white paper provides information for every operator to draw upon when setting up suitable and robust risk-based inspection intervals as part of their distribution integrity management program. These results should be appropriately combined with operator-specific data and knowledge to form the basis for inspection intervals and the overall assessment program.

1. Introduction

White Paper Organization



Introduction

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New York State Operator Data on Indoor Leak Rates

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Risk-Based Considerations and Conclusions

Section 6

2. Background

New York State DPS has notified New York state utilities of a change in code which will likely occur in the near future (within the next several months) which will update the definition of “Service Line” under Part 255.3(29) to mirror the Federal definition under Part 192. This essentially changes the existing service line definition which limits Operator responsibility for jurisdictional piping at the first fitting inside the building wall relative to the Federal definition which includes jurisdictional responsibility to the outlet of the meter, regardless of who owns the piping within the building.

Recognizing the complexity of this transition and obvious challenges associated with the practicality of the transition, Operators formed a collaborative through the Northeast Gas Association to explore reasonable alternatives to implementation that meets both the intent of the current Federal definition. More specifically, Operators suggested that there may be an opportunity for adopting a practical approach to implementation under current Distribution Integrity Management provisions. Based on technically based risk assessment, this approach includes reassessment of intervals for certain operational and maintenance requirements, specifically to extend the timeframe between inspections for mandated atmospheric corrosion inspections and leak surveys. Furthermore, Staff has informed the Company that any work on jurisdictional piping (up to the outlet of the meter) under this rule change can only be conducted by qualified personnel under mandated OQ requirements including drug & alcohol testing.

To illustrate the complexity of this issue, as of 2013, one NY State operator, National Grid, has approximately 902,782 active indoor services state-wide. This rule change would therefore involve inspection through the outlet of the meter(s). These installations include a variety of configurations and locations within the premises from simple single family meters at the inside front wall, single family meters located remotely in apartments in multifamily dwellings, through complex multi-meter sets in remote/or high level meter rooms in high rise buildings with customer-owned, concealed piping systems.

Indoor piping configurations range, again from the simple, exposed meters in basements of single family homes, through complex piping configurations including concealed piping behind permanent walls in pre-engineered pipe chases. Many of these designs were installed in accordance with long standing State regulatory practices; and in cases like NYC or other urban areas, in accordance with local building codes by certified HVAC or plumbing contractors in accordance with the minimum requirements of NFPA 54 (National Fuel Gas Code) and/or IFGC (International Fuel Gas Code) and in accordance with the utility’s specifications. Additional layers of regulatory and jurisdictional oversight to further ensure safety associated with customer owned indoor piping installations is provided by various processes throughout the State via local code enforcement.

The implications of these code changes will be substantial and will impact every Operator throughout the State.

3. Atmospheric Corrosion

Atmospheric Corrosion Definition and Categories (Outdoor)

Definition

Atmospheric corrosion can be defined[1] as the corrosion of materials exposed to the air and its pollutants, rather than immersed in a liquid.

Macro Level Categories

A customary way to categorize the types of atmospheric corrosion is by "macro environments"[2]:

- *Rural* – least corrosive, little to no chemical pollutants but may have organic and inorganic particles; corrodants are moisture, oxygen, and some CO_2. Arid and/or tropical types of environments are special cases of the rural category. The rural environments are typically benign except near farm areas where there are waste materials. Arid areas may have low/no rain, but high relative humidity and condensation. Tropics have high temperature and relative humidity, intense sunlight, and long periods of condensation during night.
- *Urban* – similar to rural, i.e., little or no industrial activity; additional contaminants are SO_x and NO_x (the backbone of smog in cities) from motor vehicle and domestic fuel emissions.
- *Industrial* – associated with heavy industrial manufacturing facilities and can contain SO_2. When combined with moisture leads to sulfurous acid which is oxidized to sulfuric acid which leads to acid rain, NO_x, acid chlorides (especially problematic), phosphates, and nitrates.
- *Marine* – includes fine, wind-swept chloride particles, deposited on surfaces; usually highly corrosive and significantly dependent on wind direction, wind speed, and the distance from the coast.

Typical atmospheric corrosion rate ranges for steel in these environments are listed in Table 1 below.

Table 1. Typical Corrosion Rate Ranges for Steel in Macro Environments[3]

Macro Environment	Corrosion Rate µm/yr
Rural	4 – 60
Urban	30 -70
Industrial	40 – 160
Marine	64 - 230

Micro Level Categories (could include indoor)

The above, macro level categories are typed according to various generalized corrosivity classifications on the large, macroscopic level. However, specific information about atmospheric corrosivity and corrosion rates is often required on the "micro" level, i.e., the small, local scale. This could include components in the process control room of a petrochemical plant (indoor environment, regardless of the macro environment) or historic items on display in the indoor atmosphere of a museum.

Wet vs. Damp Categories

Another way to assign a type to atmospheric corrosion is to designate damp vs. wet atmospheric corrosion. Where:

- *Damp* – includes microscopic "invisible" electrolyte (moisture) films created at critical humidity levels.
- *Wet* – includes visible electrolyte layers on the surface, associated with dew, ocean spray, rain water, water splashing, etc.

Part 1 - Atmospheric Corrosion Theory (Outdoor and Indoor)

Overview

Atmospheric corrosion must have an electrolyte. Thin-film, invisible electrolytes form on metal surfaces in atmospheric exposure when a critical humidity level is reached.

If the atmosphere is completely uncontaminated, at a constant temperature, a perfectly clean metal surface would not be expected to undergo corrosion damage at relative humidity level less than 100%.

However, in practice, due to:

- Hygroscopic surface species
- Impurities in the atmosphere
- Small temperature gradients between the atmosphere and metallic surfaces

A microscopic surface electrolyte forms at significantly lower humidity levels.

Important Physical Variables in Atmospheric Corrosion[2, 4]

Moisture

Moisture is the most important factor in atmospheric corrosion and overrides the presence of any other surface contamination.

Moisture can take the form of rain, dew, condensation, and high relative humidity; the latter two being possible indoors. Without moisture, most contaminants would have little or no corrosive effect. If the condensed moisture can collect in pockets or crevices it can accelerate corrosion.

Dew or condensed moisture is more corrosive than rain water because of higher concentration of atmospheric contaminants, hygroscopic salts, and generally lower pH values.

Fog can have low pH values (1.8 to 3.5) in highly contaminated regions leading to significant atmospheric corrosion in outdoor environments.

Water Adsorption

Water adsorption is important to understand as to how it drives critical humidity levels and how these further relate to relative humidity and dew point in the environment. For this reason a short explanation is now given, followed up by relative and critical humidity and dew point considerations.

Water may be adsorbed (onto the metal surface) in molecular or dissociated form by metal-oxygen or metal-hydrogen (OH) bonds. An aqueous phase on the metal surface acts as a solvent for gaseous constituents of the atmosphere (discussed in the next subsection). The dissolution of corrosive gaseous species in the adsorbed layer provides sites for promotion of corrosion.

At three monolayers, the adsorbed layer properties approach bulk water and relative humidity approaches close to "critical humidity."

The increase in the average number of molecular layers of water adsorbed on an iron surface with increasing relative humidity is shown in Figure 1[5].

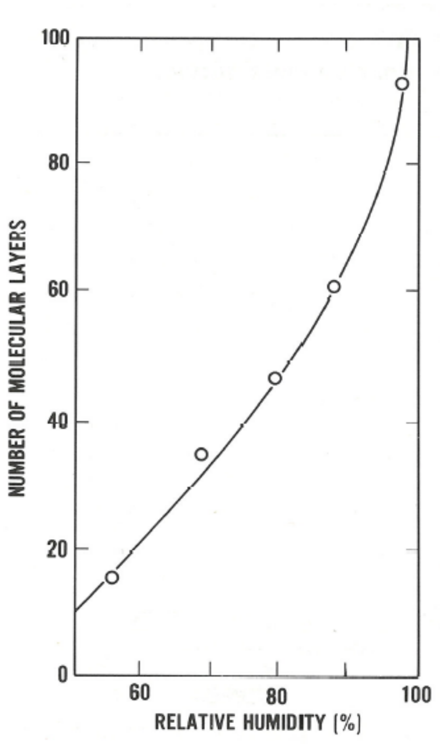


Figure 1. The relationship between the relative humidity and the number of layers of water adsorbed on an iron surface.

Relative and Critical Humidity and Dew Point

Relative humidity is the primary driver for atmospheric corrosion. There is not atmospheric corrosion in dry air. Relative humidity is defined as the amount of water vapor in the air divided by the amount of water vapor to saturate that air.

Above a material/environmental dependent critical humidity level the corrosion rate increases significantly and below this same level the corrosion rate is virtually insignificant. However, critical humidity is not a constant and depends on the material itself, the tendency of corrosion products and surface deposits to absorb moisture, and the presence of atmospheric pollutants.

If the atmosphere is clear and uncontaminated, corrosion can be negligible at relative humidity levels as high as 99%. In the presence of contaminates, corrosion rate increases around 80% relative humidity.

For iron (Fe), approximately 60% critical relative humidity level has been reported[6]. For example, Figure 2[7] shows iron to exhibit a critical humidity near 60% relative humidity when exposed in an atmosphere containing 0.01% SO_2.

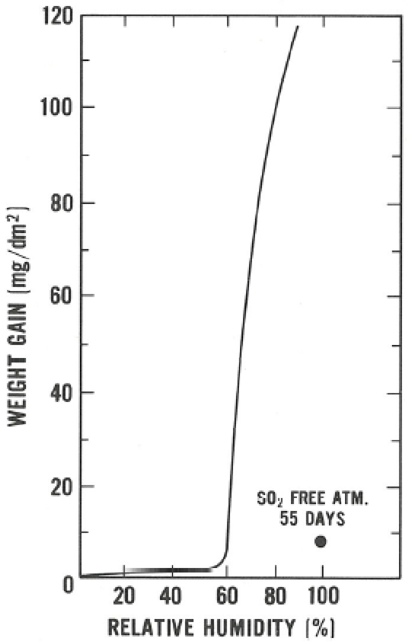


Figure 2. The relationship between the atmospheric corrosion rate of iron (by wt gain) and the relative humidity in an environment containing 0.01% SO_2.

Temperature

Temperature is important in atmospheric corrosion for two reasons.

First, there is a normal increase in corrosion activity (rate) which can double for each 10°C increase in temperature. The increase in temperature stimulates corrosive attack since the electrochemical rate and the diffusion rate both increase.

Second, there is a temperature lag of metallic objects (due to their large heat capacity) behind changes in ambient temperature. The wetness period for the metal component is usually much longer than the time the ambient air is at or below the dew (condensing) point. Temperature effects are complex in this case. For a constant relative humidity, as temperature goes up, so does corrosion rate. But in general, as temperature goes up, then relative humidity goes down and one gets more rapid evaporation of surface electrolyte, reducing corrosion. Therefore the time of wetness (explained earlier) goes down and the overall corrosion rate decreases.

An important note to indoor spaces[8] is that an increase in relative humidity associated with a decrease in temperature has an overriding effect on corrosion rate. Therefore in air conditioning, a decrease in temperature requires additional dehumidification to avoid accelerated atmospheric corrosion damage.

Cyclical temperatures can make things worse. It is advisable to have temperature 10-15°C above the dew point. Another example is in the professional coatings industry where it is typically required to have a dew point depression of 5°C or more to prevent flash rusting prior to coating (after surface preparation).

Time of Wetness

This is dependent on the critical humidity levels noted above and the presence of hygroscopic corrosion products. Capillary condensation of moisture in corrosion products, microscopic surface cracks, and at the metal surface/dust particle interface increases the time of wetness. Chemical condensation by chlorides, sulfates, and carbonates increase the amount and time of surface wetness. Finally, adsorbed molecular water layers and direct moisture precipitation increase time of wetness.

Time – Corrosion Rates as a Function of Time

Atmospheric corrosion penetration is not usually linear with time. The buildup of corrosion products often tends to reduce the corrosion rate over time. Pourbaix[9] developed the linear bilogarithmic law for atmospheric corrosion as a function of time. The law was found to be valid for rural, marine, industrial, and other macro environments. It was also valid for the following steels: carbon, weathering, galvanized, and aluminized. The law was applied in a comprehensive exposure program[10] for validation.

The bilogarithmic law is shown in equation [3].

$$\log_{10}(p) = A + B \log_{10}(t) \qquad [3]$$

p: penetration
t : exposure time
A & B are constants

It follows that the mean corrosion rate is:

$$\log_{10}(p/t) = A + (B-1) \log_{10}(t) \qquad [4]$$

The instantaneous corrosion rate is:

$$\log_{10}(dp/dt) = A + \log_{10}(B) + (B-1) \log_{10}(t) \qquad [5]$$

The initial corrosion rate, say during the first year of exposure is A; while B or (B-1) is a measure of the long-term decrease in corrosion rate.

When:

- B = 0.5, corrosion penetration is parabolic, with diffusion through the corrosion product layers as the rate controlling step.
- B << 0.5, corrosion products are protective or passivating.
- B > 0.5, non-protective corrosion products exist, e.g., loosely adherent, flaky rust layers.

The validated bilogarithmic law and Equations 3, 4, and 5 above can be used by operators to help establish appropriate indoor atmospheric corrosion levels. By consulting historical and new data, the constants in law can be determined for each macro and/or micro environment class and then the relation can be used to predict metal loss rates.

Distance from Source of Contaminant or Pollutant

This is especially important from sea salt mists and contamination around coastal areas. Fallout of salts can be 0.34 to 0.45 kg/m^2 yr in coastal areas, but are reduced to 5.62 x 10-4 kg/m^2 yr in inland areas[3].

At a distance inland of 10km or more, corrosion rate is the same as observed farther inland.

Important Pollutant Variables in Atmospheric Corrosion[2, 11]

Sulfur Dioxide (SO_2) – Acidification and Autocatalytic Attack

SO_2 is a product of the combustion of sulfur containing fossil fuels. It is more common in urban and industrial macro atmospheres.

It is adsorbed on metal surfaces and has a high solubility in water leading to the formation of sulfuric acid in the presence of such surface moisture films leading to accelerated corrosion from depressed pH.

The above acidification of SO_4^{2-} is a secondary effect and concern compared to main driver for corrosion which is the autocatalytic attack of the formed sulfate (SO_4^{2-}) ion. SO_2 forms SO_4^{2-} ions in moisture layers via an oxidation reaction per equation [1].

$$SO_2 + O_2 + 2e^- \rightarrow SO_4^{2-} \qquad [1]$$

The two electrons are supplied by anodic dissolution reaction of ferrous iron ions to ferric iron ions. Ultimately the Fe ions combine with the SO_4^{2-} ions and form iron sulfate, $FESO_4$. However, $FeSO_4$ hydrolyzes per equation [2] producing iron hydroxide corrosion product and releasing the SO_4^{2-} to continue with autocatalytic attack (it is not consumed in the reaction to a stable product, rather it continues to act as a corrosive agent, over-and-over again).

$$FeSO_4 + H_20 \rightarrow FeOOH + SO_4^{2-} + 3H^+ + e^- \qquad [2]$$

This can result in a severe atmospheric corrosion reaction.

The relationship between relative humidity and pollutants like SO_2 is very important[12]. Figure 3 shows the adsorption behavior of SO_2 on iron. At relative humidity below 80%, the SO_2 adsorption rates decreased with time and approached zero and corrosion was not observed. At relative humidity above 80%, SO_2 adsorption rates initially decreased, subsequently increased, and ultimately attained a constant value. However, above 80% relative humidity, SO_2 adsorption was accompanied by the onset of corrosion and the corrosion products formed showed a high SO_2 adsorption capacity.

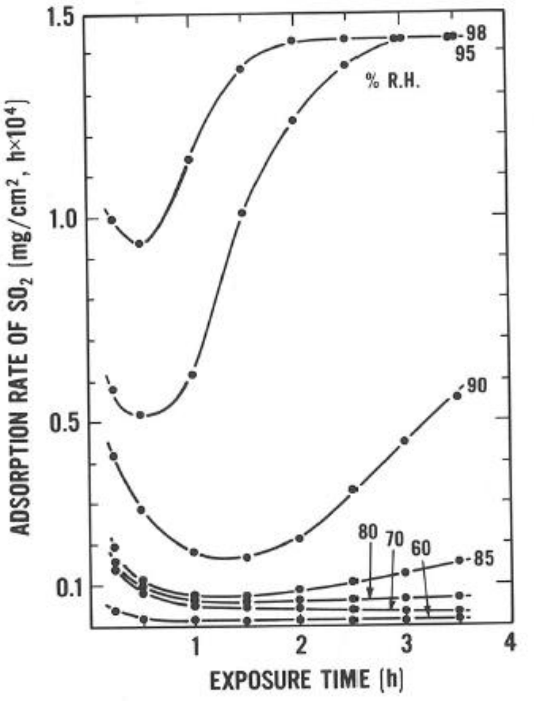


Figure 3. The relationship between the relative humidity and the rate of adsorption of SO_2 on an iron surface.

Chlorides (salt anions in solution vs. chlorine-based gas)

Atmospheric salinity directly increases atmospheric corrosion rates. This is due to:

- The salts enhancing surface electrolyte formation via hygroscopic salts such as NaCl and $MgCl_2$.
- The direct participation of chloride ions in electrochemical corrosion reactions.
- In iron-based metals, such as steel, chloride anions compete with hydroxyl ions to combine with ferrous cations. However, hydroxyl ions produce stable species, but iron-chloride complexes tend to be unstable and soluble and therefore cause further attack.

An example of air pollutant depositions for SO_2 and NaCl are shown in Table 2 below[3].

Table 2. Air Pollutants SO_2 and NaCl Depositions

Macro Environment	SO2 g/m^2 day	NaCl mg/m^2 day
Rural	< 0.01	< 0.3
Urban	0.01 – 0.1	< 0.3
Industrial	> 0.01	0.3 – 2,000
Marine	> 0.01	> 2,000

There is a relationship between the corrosion of iron and steel and the concentration of chloride salts on the surface[13], see Figure 4.

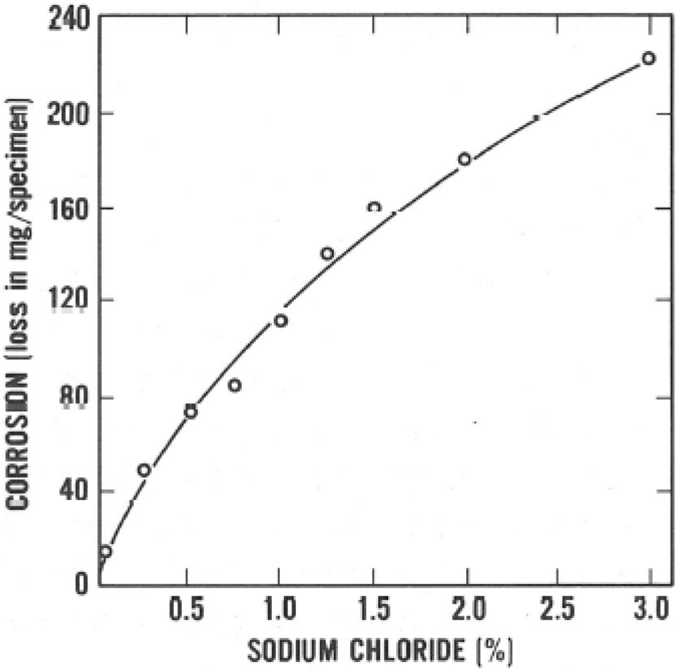


Figure 4. The dependence of the corrosion rate of steel in contact with NaCl particles at 40°C and 89% relative humidity. A three week exposure with the NaCl concentration of a solution dried onto the surface of the steel in a vacuum.

As with SO_2, there is a dependence of the corrosion rate of steel in contact with chlorides or sea salt on the relative humidity[14], see Figure 5 which shows the variance in corrosion rate over a range of humidity from 20% to 80%.

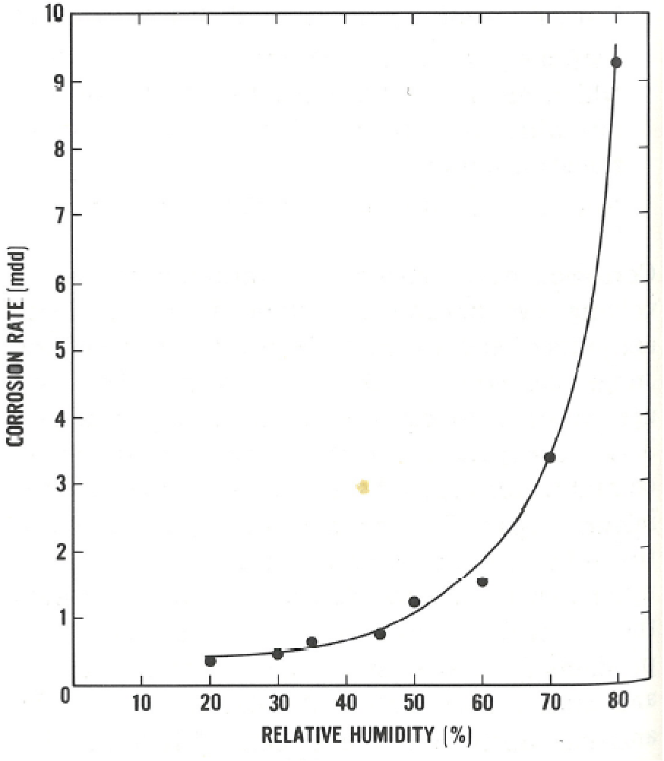


Figure 5. The dependence of the initial corrosion rate of steel in contact with particles of sea salt (~0.7 g/cm) on the relative humidity; thirteen day exposure.

For seashore locations, the outdoor corrosion rates of steel or iron components vary as functions of the distance from the seashore, see Figure 6 [15]. This figure illustrates the variation in corrosion rate as a function of air salinity and the effects of a natural process occurring within a climatic division on atmospheric corrosion.

General considerations of climate may provide qualitative information regarding atmospheric corrosion, its severity is dominated by factors specific to the local service environment.

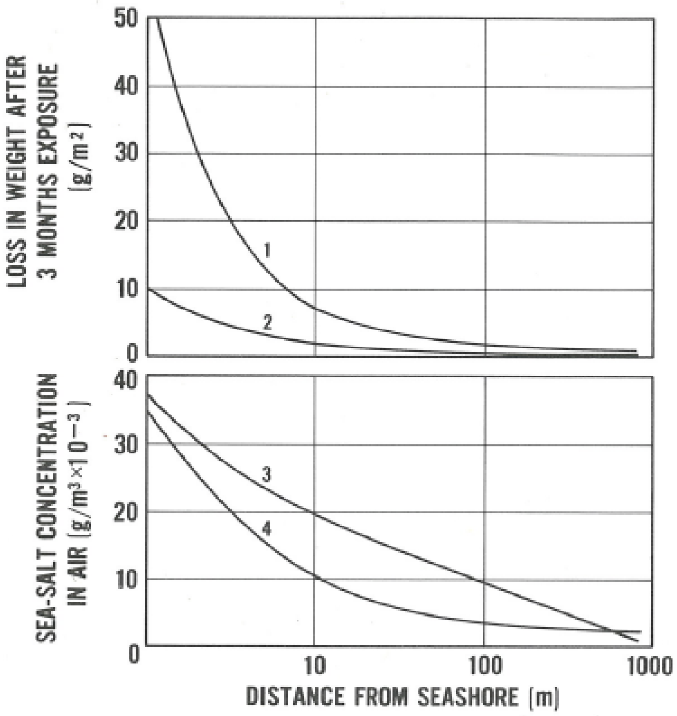


Figure 6. The corrosion rates of galvanized steel (curve 1) and cadmium coated steel (curve 2) and the corresponding air salinities (curves 3 and 4) as functions of the distance from the seashore.

Chlorine, Hydrochloric, and H_2S Gases

Cl(g) and HCL(g) in the presence of moisture are stronger corrosive agents than the above chloride salt anions due to their acidic nature. H_2S(g) is extremely corrosive to metals for the same reason.

NO_x

NO_x from combustion processes accelerates iron corrosion.

The typical outdoor range of air pollutants (in ppm) is shown in Table 3 below[3].

Table 3. Typical Outdoor Air Pollutant Range (ppm)

Pollutant	Outdoor Concentration Range (ppm)
H_2O_2	10 - 30
SO_2	1 - 65
H_2S	0.7 – 24
NO_2	9 – 78
NH_3	7 – 16
HCL	0.18 – 30
HCOOH	4 - 20

Solid Matter (particulates)

Solid matter deposition can have significant effect on atmospheric corrosion rates, particularly in the initial stages of corrosion. Impurities from emissions, like CO_2 and CO, are adsorbed in dust particles and create micro-corrosion cells.

Solid matter such as particles and dust, can stimulate corrosion attack by:

- Reduction in critical humidity levels by hygroscopic action; they can adsorb salts, promoting corrosion
- Providing anions, therefore stimulating metal dissolution to combine with these anions
- Establishing a microgalvanic effect by noble deposits, e.g., carbonaceaous deposits (e.g., soot) especially when related to iron-based materials.

The effects of carbon particles on steel specimens in environments containing SO_2 are shown in Figure 7. At low relative humidity, the presence of carbon particles accelerates corrosion by adsorbing water and SO_2 from the environment[16].

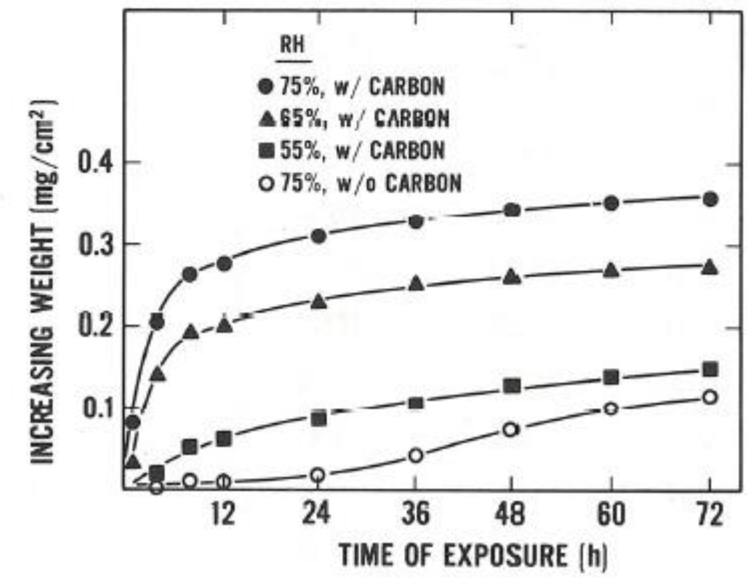


Figure 7. The effect of the presence of carbon particles on the initial corrosion rate of iron (wt gain) exposed to an environment containing 0.015% SO2 at various relative humidity.

Common emissions from natural and industrial sources can be found in applicable an ANSI/ISA standard[17].

Part 2 - Characteristics of Indoor Atmospheric Corrosion vs. Outdoor

General Distinctions

Indoor atmospheres are generally considered to be quite mild when ambient humidity (e.g., relative humidity) and other corrosive components are under control[11].

While there is no defined typical containment or set of conditions associated with an "indoor" atmosphere, any enclosed space which is not evacuated (vacuum) or filled with a liquid can be considered an indoor atmosphere.

Characteristics of indoor corrosion may differ greatly from those of outdoors. As a result or different environmental conditions, the corrosion rates are generally found to be lower indoors than outdoors. The comparatively low indoor atmospheric corrosion rates have little influence on the structural integrity of most materials[18].

Indoor environments are not just outdoor environments without the rain; rather they differ substantially with respect to a large number of environmental parameters. A brief discussion of a few of these will be given directly below. A more detailed discussion is given in the next subsection, with peer reviewed data and analysis from large and detailed field studies on outdoor vs. indoor corrosion of steel in multiple climates.

Environmental Parameters – General Difference between Indoor and Outdoor

Relative Humidity and Temperature

Indoor relative humidity and temperature depend first on the degree of ventilation. A high degree of ventilation makes indoor values closer to outdoor. Second, the degree of heating, thermal isolation, and air conditioning, in general, decrease indoor relative humidity and may increase indoor temperature.

Representative indoor relative humidities range from 15%-85% with an average close to 50%. However, variation in relative humidity and temperature are *much* less dramatic indoors than out. Variations are often more important than absolute levels for atmospheric corrosion.

Deposition Velocity

Wind velocities are normally lower indoors than outdoors by an order of magnitude, leading to lower corrosion and deposition of species.

Atmospheric Gases

This is complex for both outdoors and indoors and is discussed with robust sets of empirical data in the next subsection of this paper.

Atmospheric Particles

Coarse particles in office, multi-family housing, and commercial buildings are usually much lower than outdoors due to air filtration systems. In homes with no filtration, these particles will be higher than office buildings, but lower than outdoors.

Fine particles in offices and homes are 20%-50% of outdoor concentrations.

In general, (indoor/outdoor) ratios, with no indoor sources, are typically 0.3 for fine particles and 0.05 for coarse particles.

Given the difference in concentrations of corrodants and environments one would expect corrosion rates to vary substantially from outdoor to indoor, with indoor being substantially lower. The variations in relative humidity are less dramatic indoors than out, this also includes unconditioned basements which have the moderating effect of the stable ground temperature (heat source and sink). Additionally, the deposition velocities and concentrations of gas or particle corrodants are generally lower, sometimes substantially. This leads to relatively low indoor corrosion rate of many metals, including iron, when indoors. Mean indoor corrosion rates can typically be 2-3 orders of magnitude (i.e., 100 to 1,000 times lower) than for outdoors[18].

Data supporting the above statement and absolute corrosion rates for iron/steel in indoor environments are presented in the next subsection.

Part 3 - Peer Reviewed Data and Analysis of Outdoor vs. Indoor Corrosion Rates

Summary of Indoor Corrosion of Metals Study in the United States, Including New York

In a seminal study performed by IBM Corporation in 1980 and reported in the prestigious Electrochemical Society[19] the indoor corrosion rate of iron and other metals was measured in eight locations in the United States, including New York City.

Particular emphasis was given to the:

- magnitude of indoor corrosion,
- indoor corrosion products,
- statistical aspects of indoor corrosion,
- indoor atmospheric parameters, and
- indoor vs. outdoor comparisons for corrosion rates and pollutant levels.

The work also measured both rates and atmospheric parameters concurrently. Insights were gained on the buffering capabilities of buildings.

Experimental Summary

Extensive sample control procedures were developed and followed.

Eight sites were selected with outdoor and indoor locations at each site. Two of the eight indoor sites did not have air conditioning. The sites are listed in Table 4 below.

It is worth noting that the excellent site selection included urban, industrial, and rural environments and included industrial sites with and without air conditioning to ensure the most severe combinations.

The three largest cities in the United States were included.

Table 4. Field Site Physical Characteristics

Site No.	Location	Outdoor Environment	Indoor Environment Air Conditioned
1	Los Angeles	Urban	Yes
2	Chicago	Urban	Yes
3	Manhattan, New York City	Urban	Yes
4	Texas	Industrial/Rural	Yes
5	Indiana	Industrial	Yes
6	South Carolina	Industrial	Yes
7	New Jersey	Industrial	No
8	New Jersey	Industrial	No

Samples were retrieved from indoor sites in 6, 12, and 18 month intervals. Testing was carried out from 1973 to 1975, a more corrosive era than modern day due to improved corrosion and pollution regulations currently in place.

Multiple scientific techniques were used to classify corrosion products, e.g., Auger electron and high-resolution x-ray photoelectron spectroscopy.

Pollutant concentrations measured (indoors and outdoors) included:

- Sulfur dioxide, SO_2
- Nitrous dioxide, NO_2
- Ammonia, NH_3
- Reduced sulfur gases, H_2S, S_8, and CH_3SH
- Inorganic (acid) chlorine gases, Cl_2 and HCL
- Airborne dust

Results of Eight City Indoor vs. Outdoor Corrosion Study

Indoor Corrosion Rates of Iron

Table 5 and Figure 8 summarize the indoor corrosion rates of iron at the eight test sites from 1973 to 1975 over three time frames (6m, 12m, and 18m).

Table 5. Indoor Corrosion Rate of Iron at Eight Test Sites

Indoor Corrosion Rate ($\mu g/cm^2$ hr x 10^4) at 6, 12, and 18 months			
Location	**6m**	**12m**	**18m**
Los Angeles	1.1	21	19.9
Chicago	31.9	23.9	16.6
Manhattan, New York City	9.73	9.82	9.91
Texas	4.78	2.01	1.83
Indiana	---	109.8	60.5
South Carolina	54	8.5	26
New Jersey	66.7	539.4	67
New Jersey	21	567	476

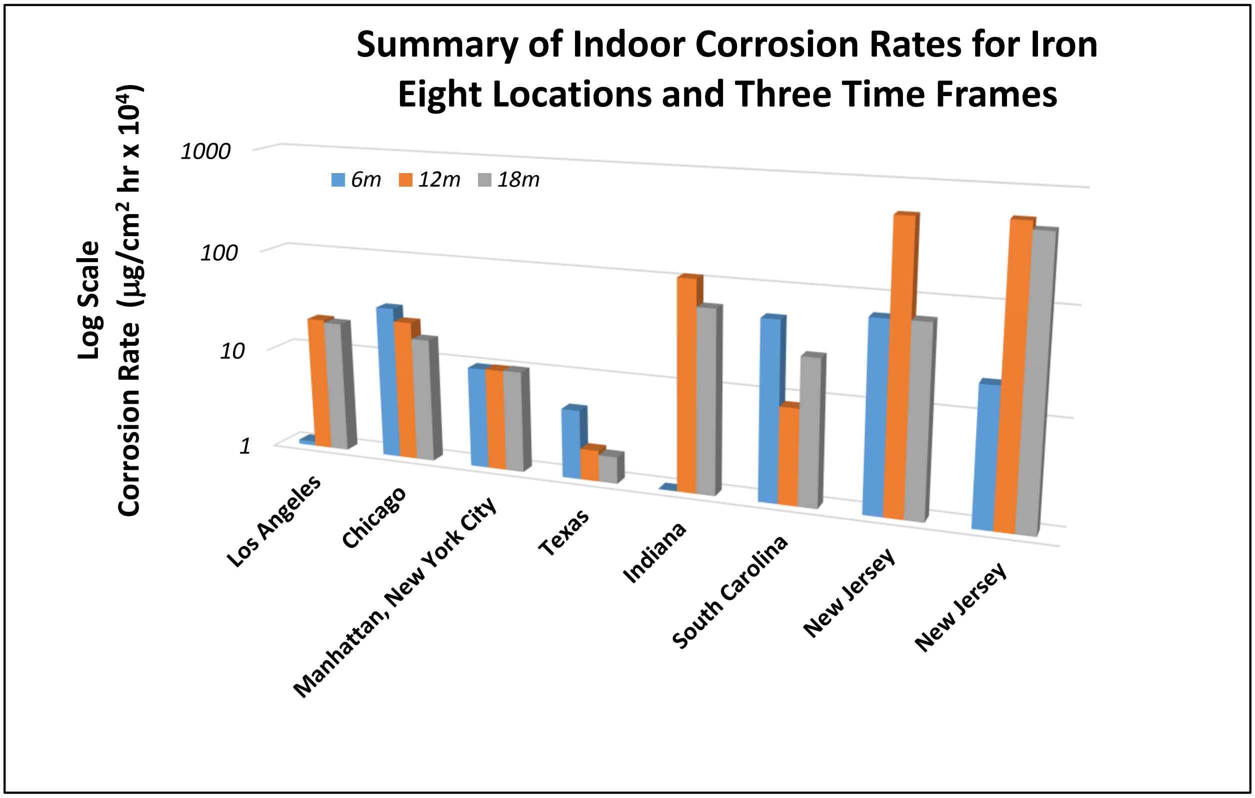


Figure 8. Indoor Corrosion Rates for Iron by Location and Time Frame (6, 12, and 18 months).

Comparison of Indoor vs. Outdoor Corrosion Rates

All the rates were further fit to a lognormal distribution and are listed in Table 6 and plotted in Figure 10 and Figure 9. These tables and figures contain the data from this study[19] and includes other reported literature for indoor and outdoor corrosion data in lognormal distribution[20,21 and22].

Table 6. Lognormal Distribution Fit for Indoor and Outdoor Iron Corrosion

Indoor and Outdoor Corrosion Rate or Fe ($\mu g/cm^2$ hr)		
Cumulative % of Measurements	**Indoor**	**Outdoor**
10	0.00026	2.5
30	0.00100	3.81
50	0.00252	5.12
70	0.00620	6.87
90	0.02316	10.5
99	0.18500	18.9
Correlation Coefficient	0.98	0.98

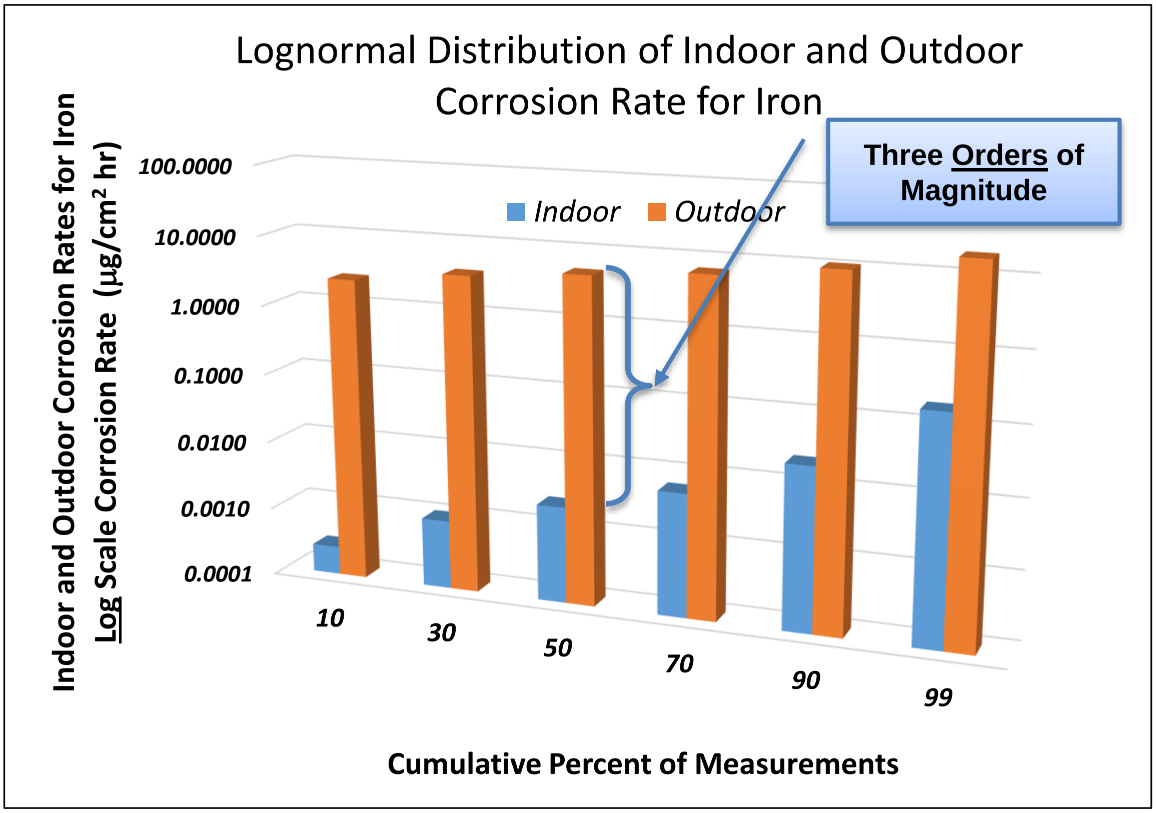


Figure 9. Lognormal Distribution of Indoor and Outdoor Corrosion Rate for Iron.

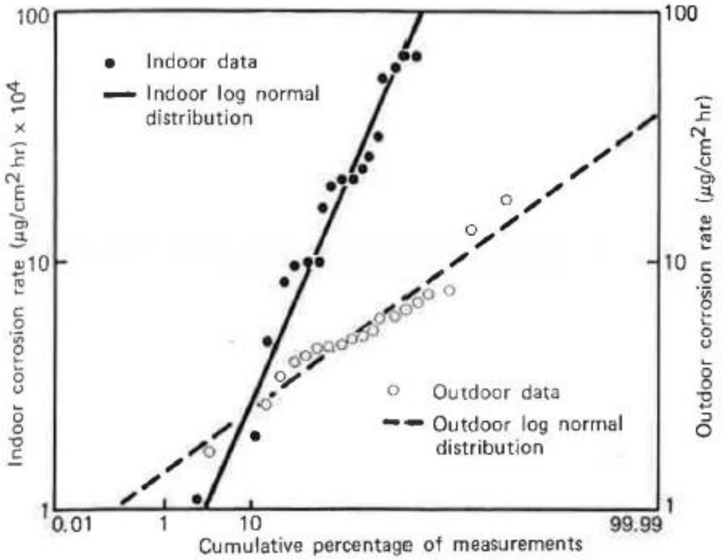


Figure 10. Iron Corrosion Rate Distribution (note vertical scale difference for indoor vs. outdoor).

Comparison of Indoor vs. Outdoor Corrosion Rates from Separate 1999 Study

To supplement the findings above, the comparative findings of another peer reviewed study[23] is presented in Table 7 and Figure 11 below. This study was done after the 1980 Rice et. al. study so is included for comparison.

Table 7. Corrosion Rates of Steel for Different Locations and Times from 1999 Study

Indoor and Outdoor Corrosion Rate or Carbon Steel (g/m^2 yr)					
Exposure Time (months)	**Outdoor**	**Sheltered**	**Ventilated Sheltered**	**Closed Space**	**Ratio Outdoor/Closed Space x 100 (%)**
6	216.70	181.40	77.20	12.50	1,734
12	223.60	175.10	58.60	3.50	6,389
18	172.20	Lost to Wind	51.60	2.40	7,175

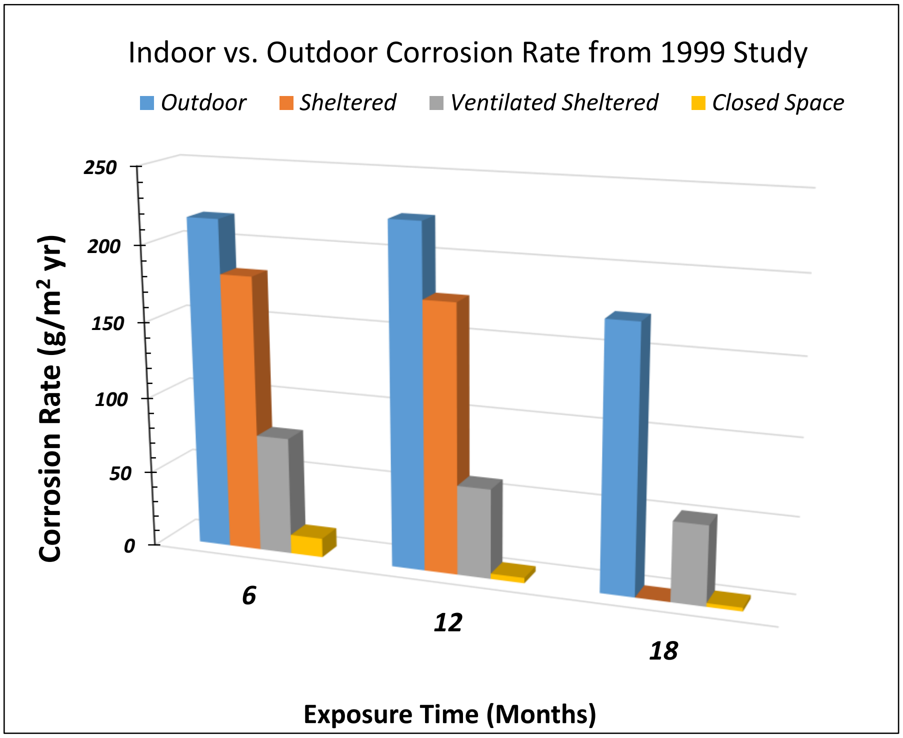


Figure 11. Corrosion Rates of Steel for Different Locations and Times from 1999 Study.

The corrosion rates for a closed space after 18 months are about 75 times lower than for outdoor conditions.

Indoor Pollutant, Dust, and Humidity Levels

Table 8 and Figure 12, Figure 13, and Figure 14 are statistical summaries of the mean pollutant levels and relative humidity (for conditioned spaces) at each site determined directly from the pollutant and humidity testing data. Figure 15 is a composite relative humidity indoor histogram for six of the sites with least squares fit to a normal distribution.

Table 8. Indoor Pollutant, Dust, and Humidity Summary

Indoor atmospheric pollutant, dust, and relative humidity statistical summary (arithmetic mean concentrations in µg/m3 for all except RH in %)							
Location	**SO_2**	**NO_2**	**Reduced Sulfur**	**NH_3**	**Chlorine Gas**	**Dust**	**RH%**
Los Angeles	2.62	55.80	0.20	12.70	0.29	17.70	50.00
Chicago	13.60	23.30	0.45	15.30	0.12	3.90	49.00
Manhattan, New York City	39.60	35.00	0.46	11.30	0.28	11.10	44.00
Texas	1.57	4.50	0.47	159.00	0.08	6.80	59.00
Indiana	12.80	25.60	0.82	18.40	0.26	22.20	55.00
South Carolina	2.10	3.01	4.24	24.70	0.16	33.00	50.00

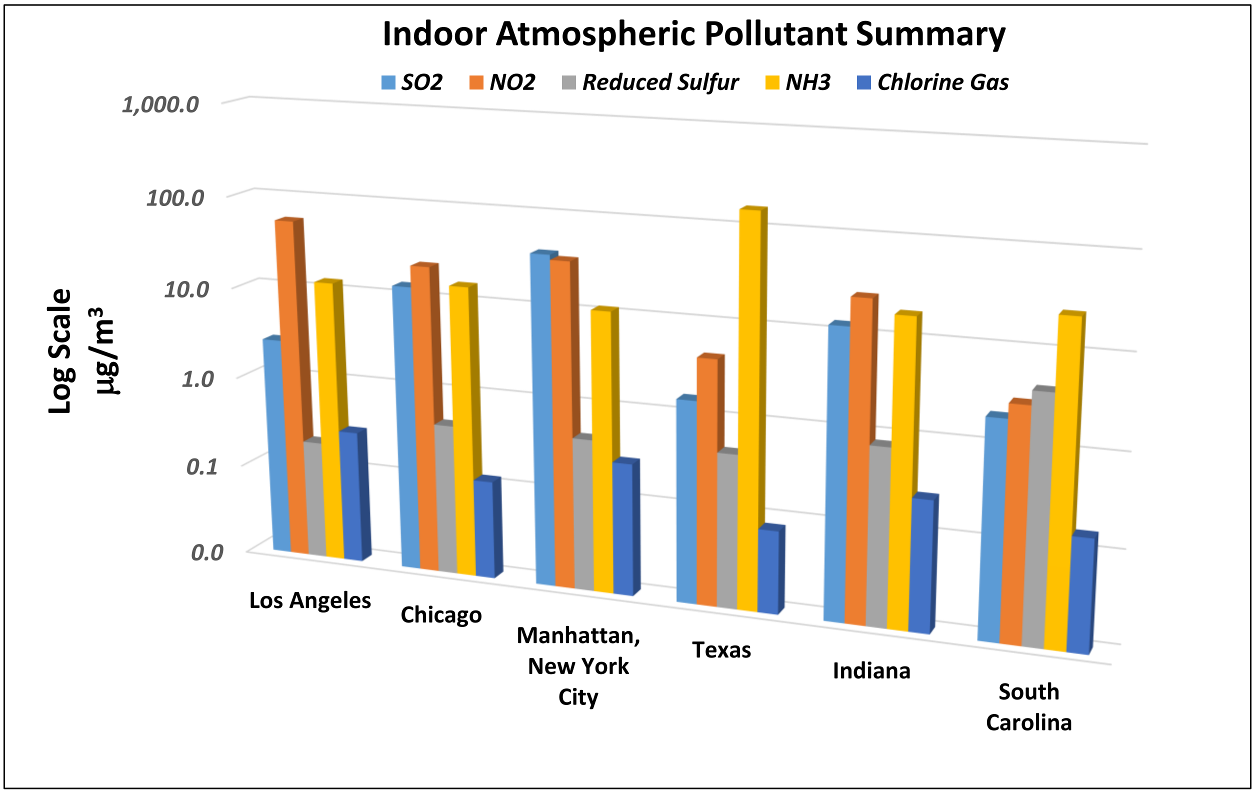


Figure 12. Indoor Atmospheric Pollutant Summary.

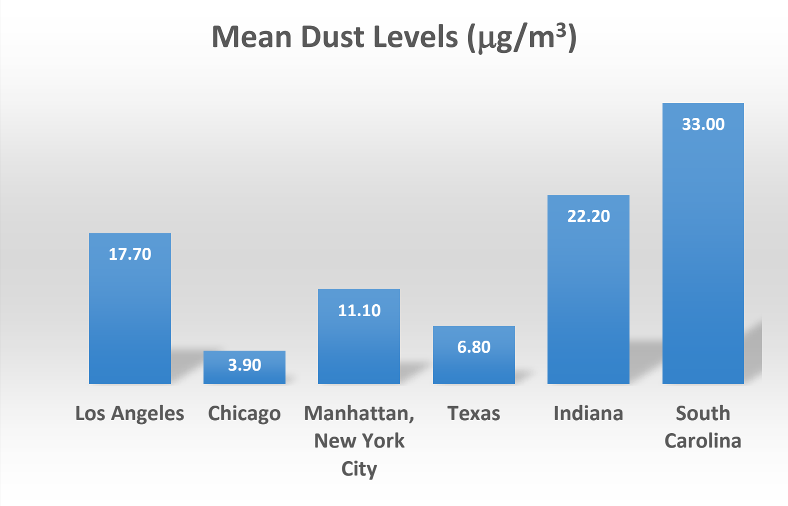


Figure 13. Mean Indoor Dust Levels by Location.

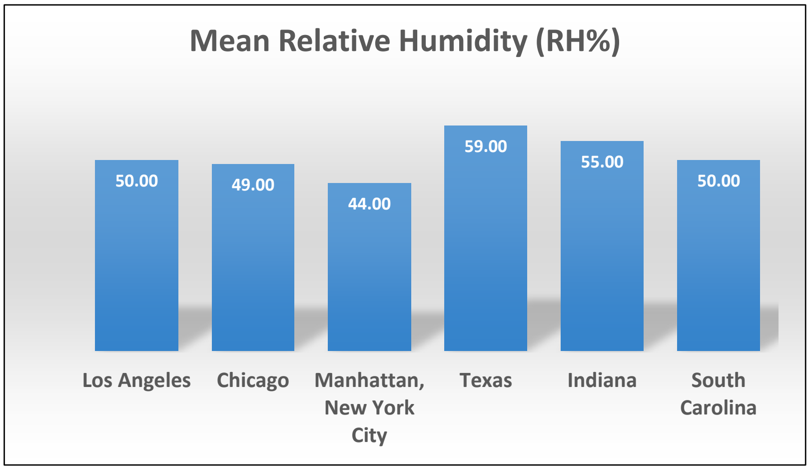


Figure 14. Mean Indoor Relative Humidity by Location.

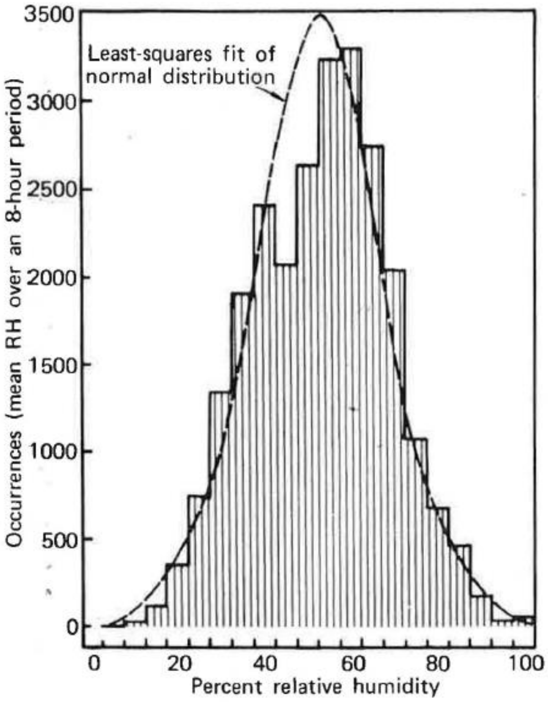


Figure 15. Composite relative humidity indoor histogram for six sites and least squares fit to a normal distribution.

Comparison of Indoor vs. Outdoor Pollutant Levels

The measured indoor pollutant mean site concentrations are generally less than the mean outdoor values in the United States except for NH_3 and reduced sulfur. Table 9 and Figure 16 summarize the mean indoor and outdoor levels as well as the ratio of indoor to outdoor concentrations.

Table 9. Comparison of Indoor vs. Outdoor Pollutant Levels

Comparison of Indoor vs. Outdoor Pollutant Concentrations (µg/m^3)

Pollutant	Indoor (Ci)	Outdoor (Co)	Ci/Co x 100 (%)
SO_2	12.20	17.60	69.00
NO_2	26.00	43.50	60.00
NH_3	14.90	10.00	149.00
Reduced Sulfur	0.48	0.48	100.00
Chlorine Gas	0.20	1.50	13.00
Airborne Dust	16.00	61.00	26.00

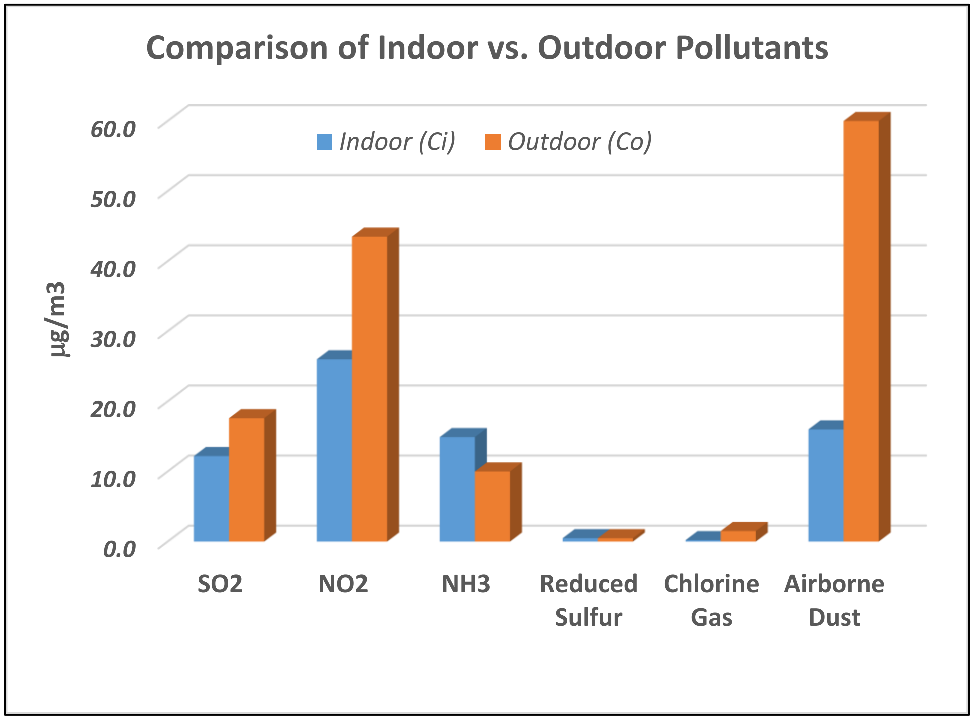


Figure 16. Comparison of Indoor vs. Outdoor Pollutant Levels.

Discussion of Eight City Indoor vs. Outdoor Corrosion Study

Metallic Corrosion

The indoor environment can significantly influence the level of each atmospheric parameter as well as its distribution or range. Pollutant concentrations are typically reduced indoors, unless a pollutant source is located within the building. The corrosion rates inside buildings are expected to be less than outside.

The indoor corrosion of iron showed a range of kinetics from parabolic at the less corrosive sites to linear at the more corrosive sites. The non-air-conditioned sites exhibited the highest corrosion rates, but were still substantially lower than outdoor conditions due to the moderating effect of the indoor atmosphere and substantially lower variability (swings) in temperature and relative humidity.

The data was fit to a lognormal distribution with an excellent correlation factor of 0.98.

Comparison of the indoor data to an outdoor distribution shown in Figure 10 shows that the indoor environment reduces iron corrosion by a factor of 1/2000.

Corrosion products for the indoor specimens were determined to be oxidized iron, sulfate, nitrite, hydroxide, oxide, and carbonate. Only one site showed chlorides.

In summary, the field metallic corrosion of iron is given in Table 10.

Table 10. Summary of Iron Field Corrosion Indoors and Outdoors

Attribute	Result
Kinetics	Linear parabolic
Corrosion Products	$FeSO_4$, OH^-, CO_3^{2-}, NO_x^-, O^{2-}
Indoor and Outdoor Corrosion Distribution	Lognormal
Indoor Corrosion Rate (50% median)	0.0025 $\mu g/cm^2$ hr
Outdoor Corrosion Rate (50% median)	5.12 $\mu g/cm^2$ hr
Ratio of Outdoor/Indoor Corrosion (50% median)	**2,045**

Corrosion of iron/steel is markedly accelerated by outdoor high humidity excursion. The marked reduction in indoor iron corrosion must be accounted for by both a reduction in high humidity occurrences and a reduction in pollutant level.

Practical Implications of Indoor Corrosion Rates and Inspection Intervals

Below is a practical comparison of the indoor and outdoor atmospheric corrosion rates presented in this paper with the typical underground corrosion rates from NACE Standard SP0502–2008, Standard Practice, "Pipeline External Corrosion Direct Assessment Methodology" (reaffirmed March 20, 2008)[24] which is incorporated by reference in the Federal Code 49CFR 192.925(b)(3).

All the rates were converted into mils/year where 1 mil is equal to 0.001 inches. This is a depth of penetration per year measurement which is most useful from an engineering standpoint. The rates selected for the indoor and outdoor atmospheric corrosion were the upper 99% confidence level (a conservative approach) [19] and the published 80% upper confidence level from the NACE ECDA methodology.

Practical Corrosion Rate Comparisons

The corrosion rates are shown in Table 11 and Figure 17 below.

Table 11. Comparison of Indoor, Outdoor, and Buried Iron/Steel Corrosion Rates (99% and 80% upper confidence levels)

Indoor, Outdoor, and Buried Corrosion Rate or Iron (mils/yr)*		
Atmospheric Indoor	**Atmospheric Outdoor**	**Buried (Underground)***
0.0811	8.2824	16

*1 mil = 0.001 inches

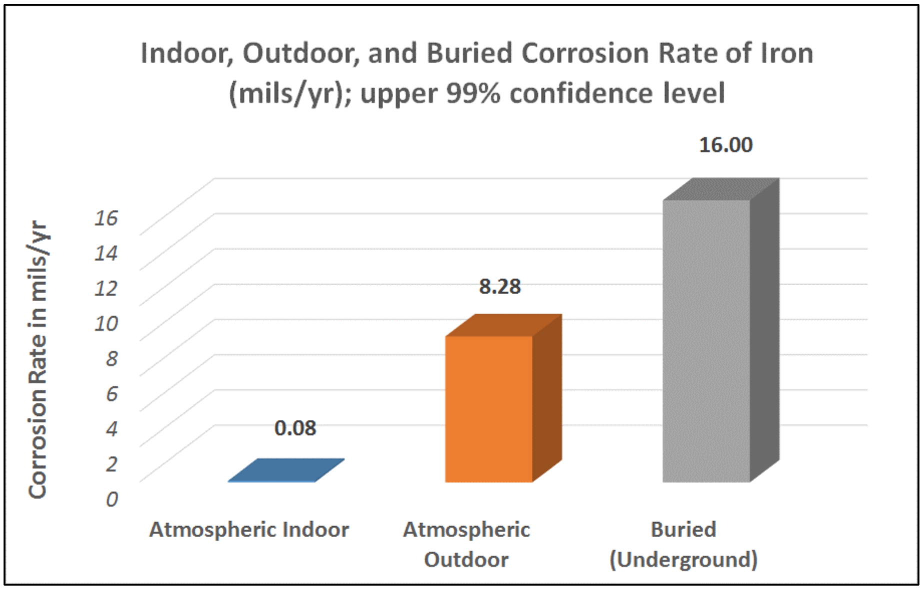


Figure 17. Indoor and Outdoor Corrosion Rates in mils/yr (99% upper confidence level) and Buried/Underground Corrosion Rate (80% upper confidence level, from NACE ECDA SP).

Practical Example of Time to Corrode Away 25% of a Pipe Wall Thickness

To demonstrate the effects of the different corrosion rates, a calculation on how long it would take to corrode away 25% of a pipe wall thickness was performed. Table 12 and Figure 18 show the number of years it would take if a ¾ inch diameter iron pipe was installed in an indoor, outdoor, and buried (underground) environment.

Table 12. Comparison of Time to 25% Pipe Wall Loss for Indoor, Outdoor, and Buried Corrosion Rates

Time in years to 25% Wall Lost of a Standard Schedule-40 3/4-inch Diameter Iron Pipe with 0.113 inch Thick Wall *		
Atmospheric Indoor Exposure	**Atmospheric Outdoor Exposure**	**Buried (Underground)**
348	3.4	1.8

***Note**: Used the upper 99% confidence level for atmospheric corrosion; used buried corrosion rate of 16 mils/yr from NACE ECDA SP which is the upper 80% confidence level as reported in the NACE standard and incorporated by reference in the code.

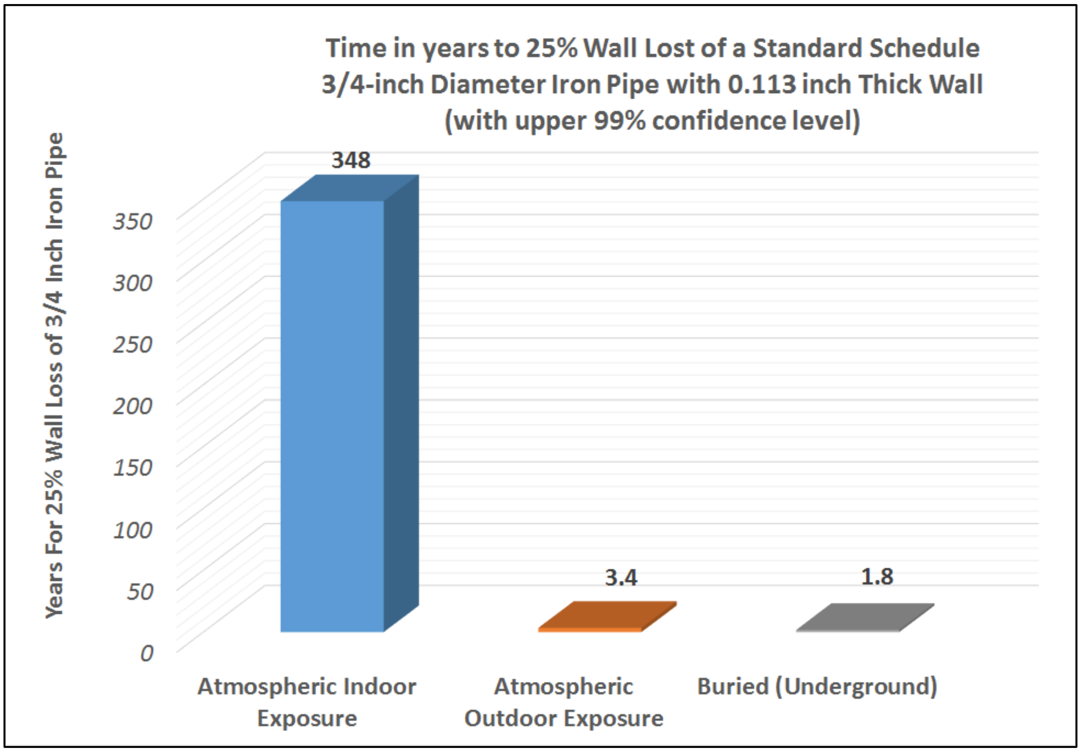


Figure 18. Comparison of Time in Years to Corrode Away 25% of ¾ inch diameter iron pipe exposed to indoor vs. outdoor vs. buried conditions.

The data shows that it would take about 100 times longer to corrode through the pipe wall at the same depth indoors as it would outdoors. It also shows that the buried conditions would corrode the same distance in about half the time of outdoor conditions.

Based on the information presented in this section and the cited references, it is evident that different, extended inspection intervals are warranted and appropriate for indoor environments vs. outdoor environments. This is discussed further, and a suggested approach is presented in the final section of this paper.

Key Findings of from the Atmospheric Corrosion Literature Review

The above Section reviewed published literature, book chapters, peer reviewed paper, published field studies, and other sources of data and information on outdoor and indoor atmospheric corrosion of iron and steel. The key findings include:

1. The peer-reviewed literature search concluded that relative humidity, and its interaction with pollutants, are the main drivers for atmospheric corrosion.
2. The variation in humidity and temperature are dramatically lower indoors than outdoors and when combined with the absolute lower humidity and pollutant levels, it results in lower corrosion rates for indoor steel and iron assets.
3. Quantitative, scientific and engineering data showed that indoor atmospheres result in an often significantly low corrosion rate than for outdoor atmospheres.
4. Mean indoor corrosion rates are reported at 2-3 orders of magnitude (100 to 1,000 times) lower than outdoor rates.
5. The validated bilogarithmic law can be used by operators to help establish appropriate indoor atmospheric corrosion levels. By consulting historical and new data, the constants in law can be determined for each macro and/or micro environment class and then the relation can be used to predict metal loss rates.
6. A seminal, multi-year indoor vs. outdoor corrosion rate study showed indoor corrosion of steel/iron to be a factor of 2,000 times lower than the outdoor corrosion rates. This study included New York, New Jersey, Los Angeles, Chicago, Texas, Indiana, and South Carolina.
7. The published work collected concluded that the marked reduction in indoor iron corrosion is accounted for by both a reduction in high humidity occurrences and a reduction in pollutant levels.
8. Different, extended inspection intervals are warranted and appropriate for indoor environments vs. outdoor environments. This is discussed further and a suggested approach is presented in the final section of this paper.

4. Operator Data – Atmospheric Corrosion Surveys

Parametric Study on Factors Affecting Corrosion

Historical records of a New York LDC (2007)[25] on indoor meter-sets population were inspected for information related to corrosion and leakage.

The field records focused on unprotected steel installations since leaks in this category have a greater potential to create a hazard quickly. A total of 182 services were included in the inspection plan and the data was recorded on standardized data sheets.

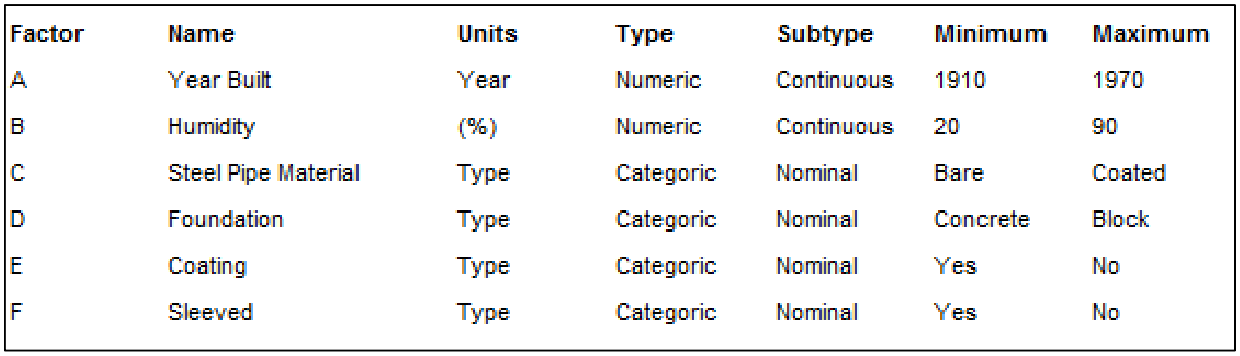
The results of 126 of these *indoor* installations were reviewed in this white paper. The data set covered a wide range of leak and corrosion observations. Pressure tests at the time of survey were also performed to a maximum of 90 psig on the through-wall service lines in these installations.

Parametric Study Parameters

A parametric study was performed on the data to evaluate the variables affecting the prediction of corrosion or leakage. The recorded parameters are listed in Table 13 and the distributions of these parameters are shown in Figure 19 to Figure 24. The data in the figures are summarized as follows:

- The indoor meter installation year, relative humidity and temperature have normal distributions. Most of the humidity records were at the 50% levels and temperatures at 70°F in the indoor installations.
- Although the majority of the pre-1970 installations were initially 'bare' steel installations, some of these pipes are fully or partially coated during the process of consequent repairs and replacements.

Table 13. Factors Investigated in the Indoor Meter-Sets Study



Factor	Name	Units	Type	Subtype	Minimum	Maximum
A	Year Built	Year	Numeric	Continuous	1910	1970
B	Humidity	(%)	Numeric	Continuous	20	90
C	Steel Pipe Material	Type	Categoric	Nominal	Bare	Coated
D	Foundation	Type	Categoric	Nominal	Concrete	Block
E	Coating	Type	Categoric	Nominal	Yes	No
F	Sleeved	Type	Categoric	Nominal	Yes	No

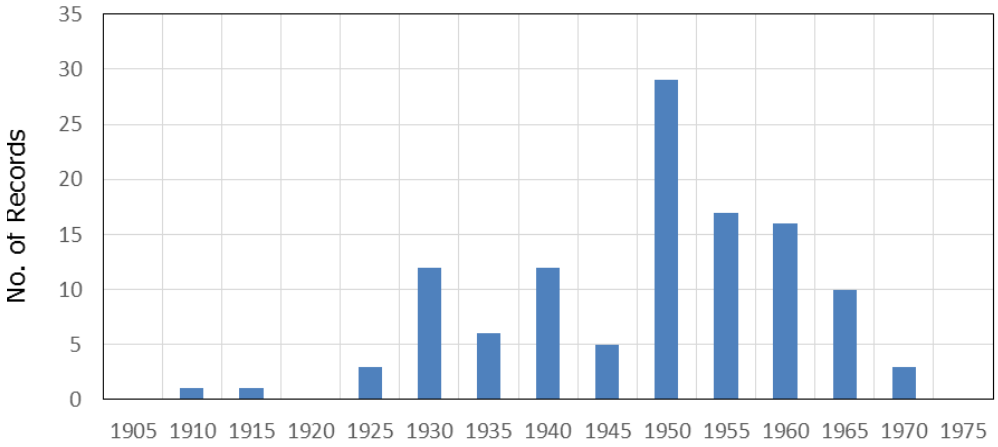


Figure 19. Indoor meter 'Installation Year' in the data set

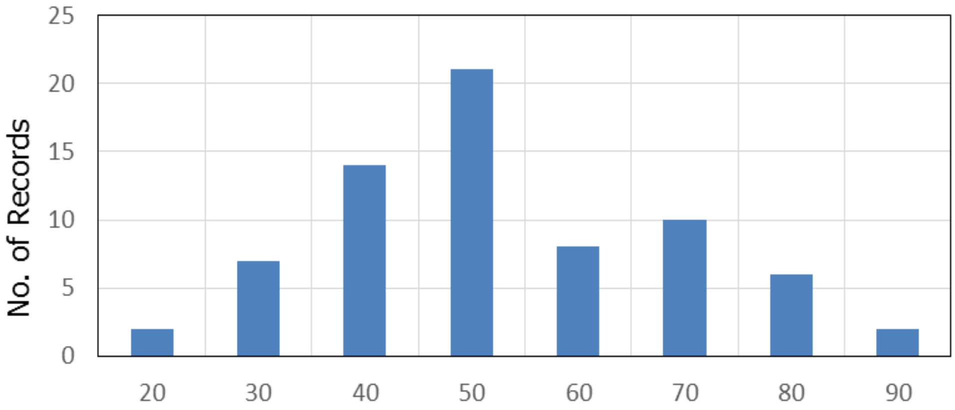


Figure 20. Distribution of the 'Humidity (%)' in the data set

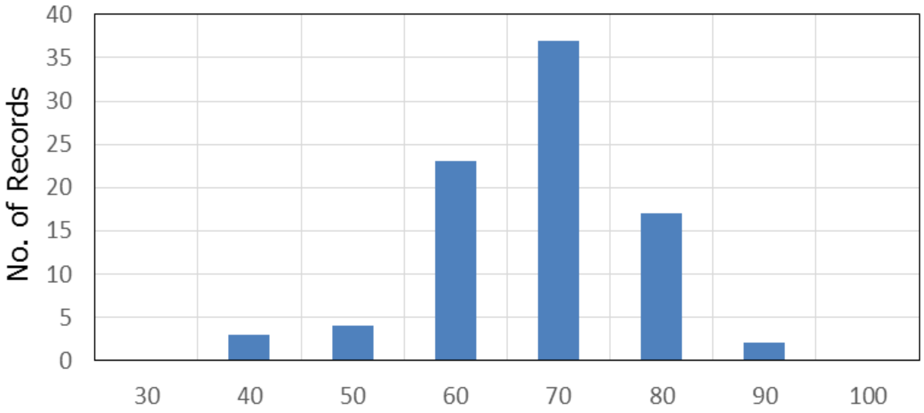


Figure 21. Distribution of 'Atmospheric Temperature (°F)' in the data set

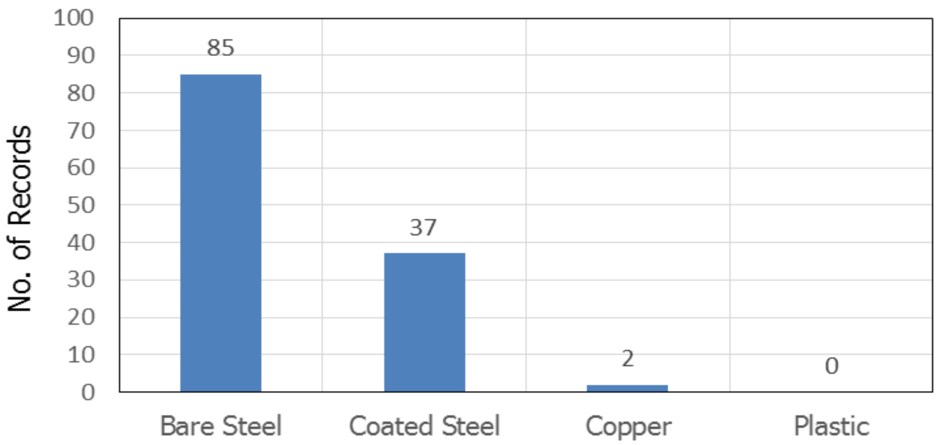


Figure 22. Distribution of the ‘Pipe Material’ in the data set

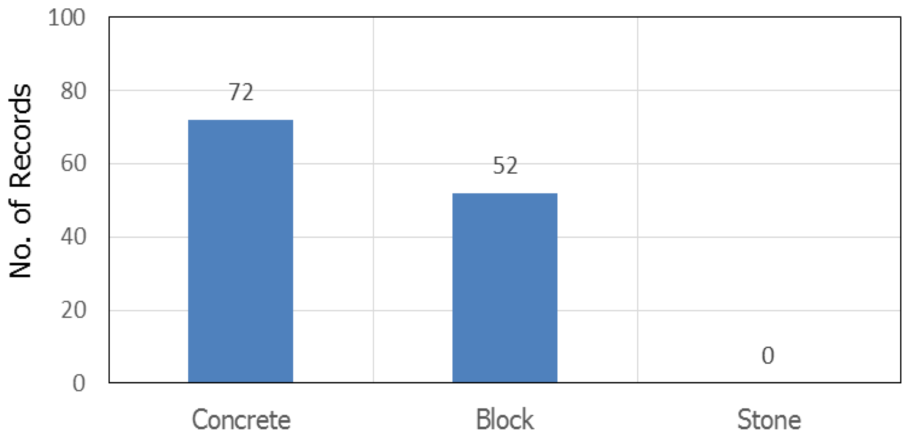


Figure 23. Foundation types in the indoor meter-sets data

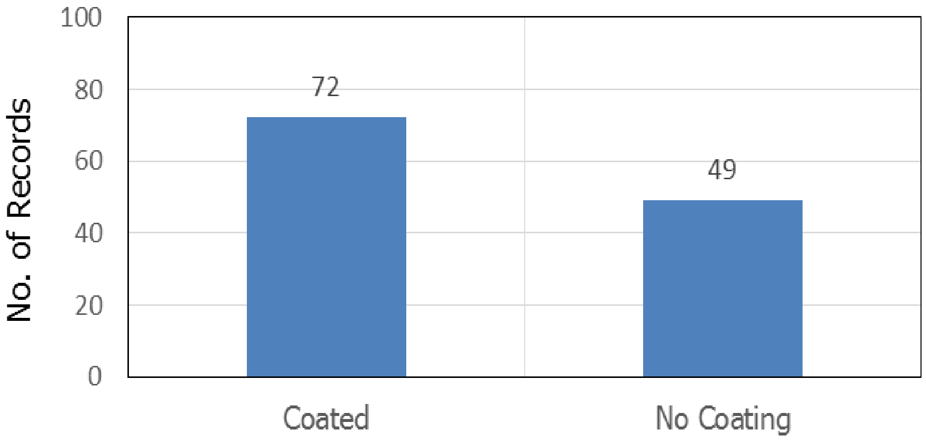


Figure 24. Piping coating types in the indoor meter-sets data

Parametric Study Responses and Condition Categories

The analysis evaluated the effect of the above parameters on the following observed responses:

- Leak record (Leak vs. No-Leak),
- Pipe Condition at wall,
- Meter piping condition, and
- Results of pressure tests (Pass vs. Fail).

The pipe and meter piping conditions were categorized from 1 to 4 with respect to their corrosion level as follows:

1. Satisfactory - no corrosion,
2. Mild oxidation, slight surface rust,
3. Slight corrosion,
4. Severe corrosion – metal loss.

Figure 25 shows the corrosion conditions of pipes and meter piping in these installations. The results show that more than 90 percent of the records had no-indication of corrosion or mild surface rust. A number of records of 8% had category 3 and a minimum number of 1% had category 4 corrosions; which prompted immediate or scheduled repairs.

With regards to the leak records, the records had 29 installations with recorded leaks and 7 failures in the pressure tests at the existing MAOP, with the rest of the installations in the 126 records passing the test.

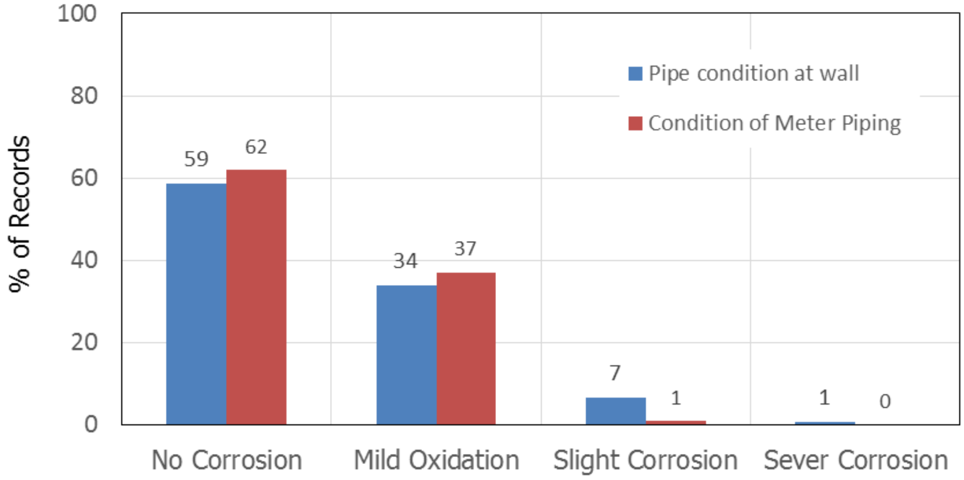


Figure 25. Meter and piping conditions in the indoor meter-sets

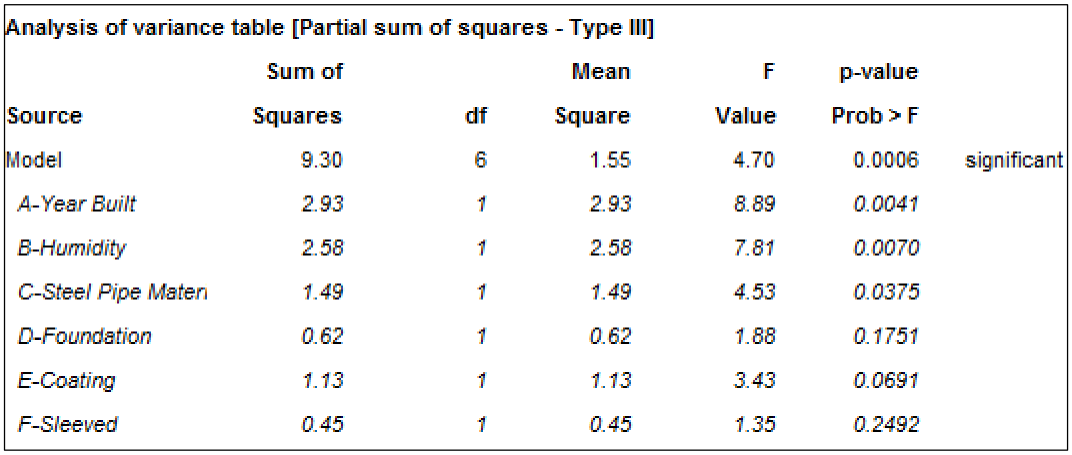
The data plotted in Figure 19 to Figure 24 were analyzed using the Analysis of Variance (ANOVA) of the Design-Expert® Software program (Design Expert 2014)[26] to investigate the statistical significance of these parameters on the leak (Section 5 of this paper) and corrosion conditions. The results of the corrosion analysis are presented below.

Significance of the Site Parameters on Corrosion

The ANOVA response analysis was performed on the effect of the parameters in Table 13 on the pipe and meter piping corrosion conditions. Table 14 and Table 15 show the effects of these parameters on the pipe and meter piping corrosion conditions, respectively.

Of importance to the analysis are the p-values of the various influencing parameters. A p-value below 0.05 indicates that the model term is significant. The results of the data analysis show that some of the model terms are not significant; indicating that there is relationship between the corrosion indications and these parameters.

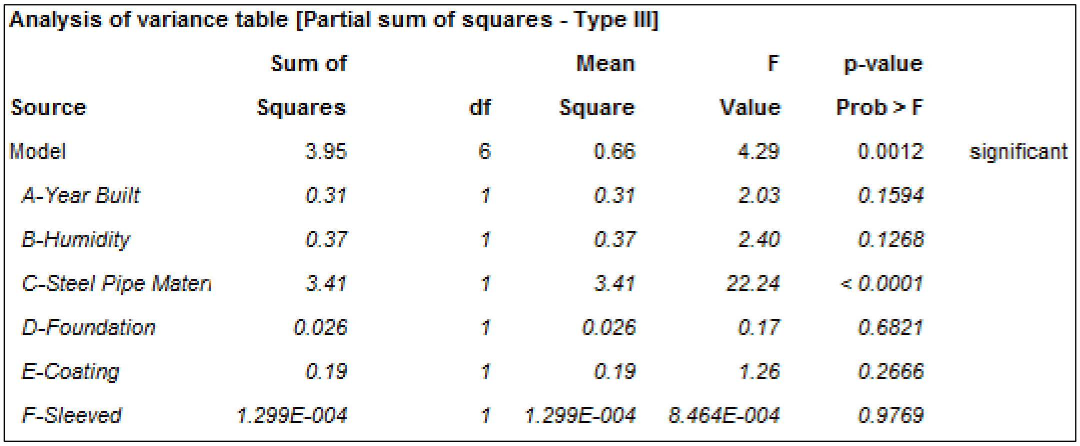
Table 14. ANOVA for Response Parameters on Pipe Corrosion (Linear Model)



Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	9.30	6	1.55	4.70	0.0006	significant
A-Year Built	*2.93*	*1*	*2.93*	*8.89*	*0.0041*	
B-Humidity	*2.58*	*1*	*2.58*	*7.81*	*0.0070*	
C-Steel Pipe Materi	*1.49*	*1*	*1.49*	*4.53*	*0.0375*	
D-Foundation	*0.62*	*1*	*0.62*	*1.88*	*0.1751*	
E-Coating	*1.13*	*1*	*1.13*	*3.43*	*0.0691*	
F-Sleeved	*0.45*	*1*	*0.45*	*1.35*	*0.2492*	

Table 15. ANOVA for Response Parameters on Meter Piping Corrosion



Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	3.95	6	0.66	4.29	0.0012	significant
A-Year Built	*0.31*	*1*	*0.31*	*2.03*	*0.1594*	
B-Humidity	*0.37*	*1*	*0.37*	*2.40*	*0.1268*	
C-Steel Pipe Materi	*3.41*	*1*	*3.41*	*22.24*	*< 0.0001*	
D-Foundation	*0.026*	*1*	*0.026*	*0.17*	*0.6821*	
E-Coating	*0.19*	*1*	*0.19*	*1.26*	*0.2666*	
F-Sleeved	*1.299E-004*	*1*	*1.299E-004*	*8.464E-004*	*0.9769*	

The results in the above tables show that:

- Pipe age, percentage of humidity, and pipe type (i.e., bare vs. coated steel pipes) are significant parameters affecting pipe corrosion condition; with p-values below 0.05 for these three parameters as shown in Table 14. These values indicate that there is a strong relationship between these parameters and pipe corrosion.

- Figure 26 shows the increase of pipe corrosion levels (i.e., to higher corrosion categories in the Y-axis) in older pipes and with the increase of the humidity level. These liner relationships provide a simplified estimate of the expected level of corrosion based on these two parameters.

- Foundation type and the presence of sleeves or applied coatings were not significant terms to affect either the pipe or the meter piping corrosion conditions.

- The age of the pipe and humidity were less significant for the *meter* piping corrosion conditions as shown in Table 15.

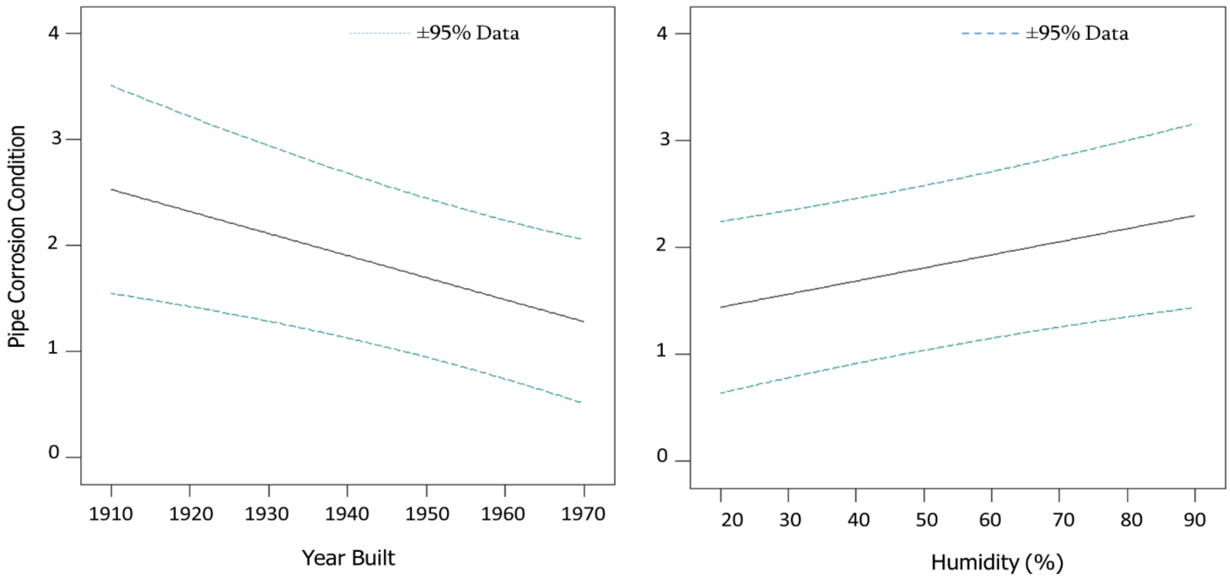


Figure 26. 3-D Response Surface of pipe condition with age and humidity

The utility repair records in the States of MA and NY were investigated for the period from 2007 to 2008 to evaluate the percentages of indoor atmospheric corrosions, their severity, and the parameters associated with their occurrences.

These records were extracted from the monthly work-record databases which cover both indoor and outdoor service work. The data covered a wide range of service work (e.g., changing meters and regulators, locking and unlocking services, repair and replace valves and regulators, and repair leaks). Visual investigation, categorization, and repair of atmospheric corrosion was performed and recorded in most of these records.

Source and Categories of Survey Records

The percentages of the records where corrosion investigations were performed are shown in

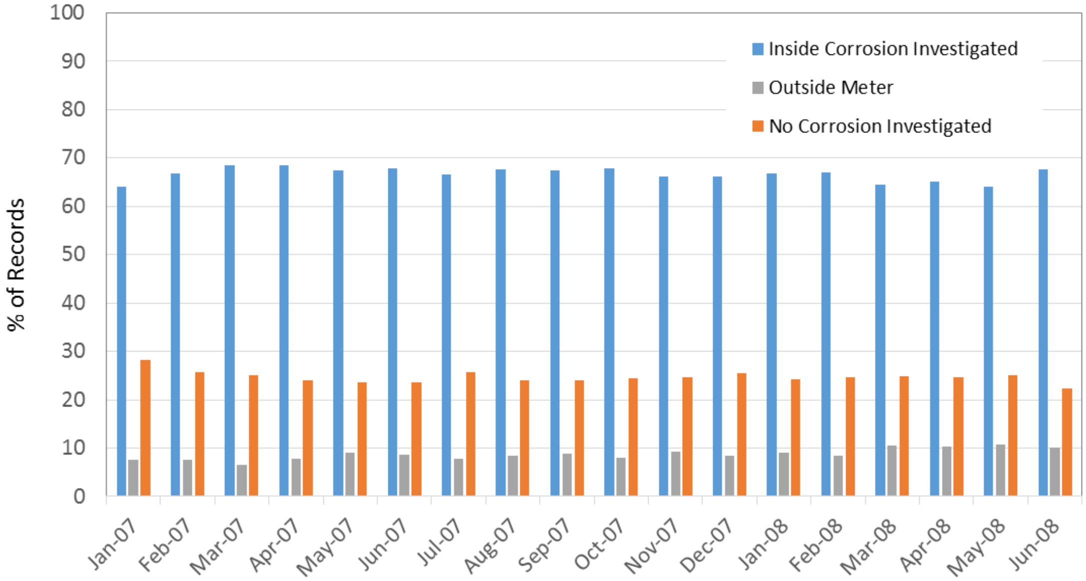


Figure 27. The figure shows the percentages of the corrosions investigated in all the work records for New York City. The figure can be summarized as follows:

- The investigation for corrosion conditions in the piping systems was performed in about 80% of the records, regardless to the type of job performed in the site.
- Out of the 80% investigated sites, about 70% of the investigations were performed on indoor installations while the remaining 10% were in locations with outside meters.
- The remaining 20% of the records (No-Corr. Investigated) included jobs performed in other parts of the house and at locations with no access to piping.

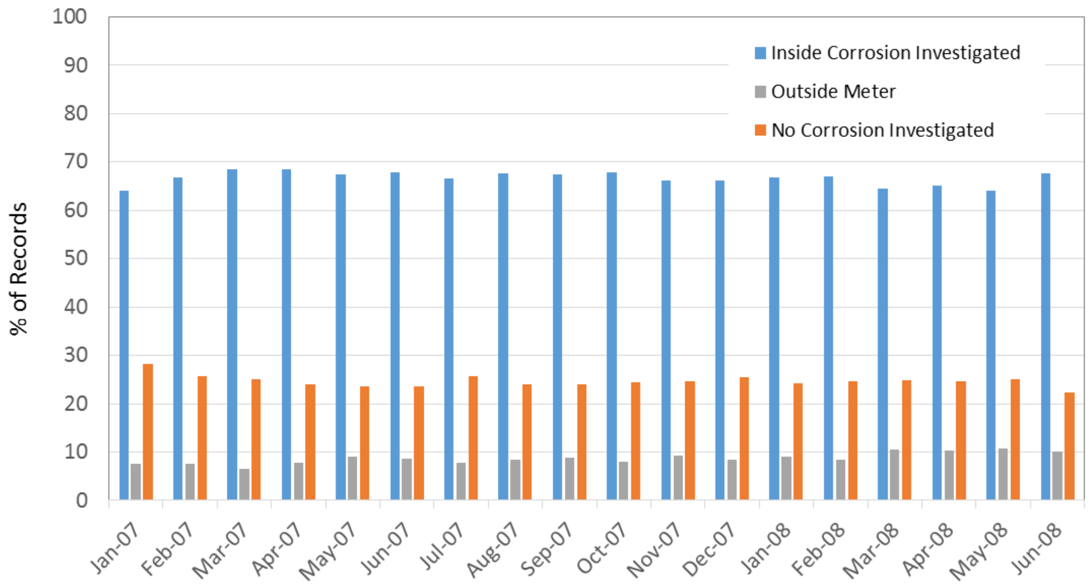


Figure 27. Percentages of investigated corrosion in all work records [2007-2008]

Corrosion Condition Categories

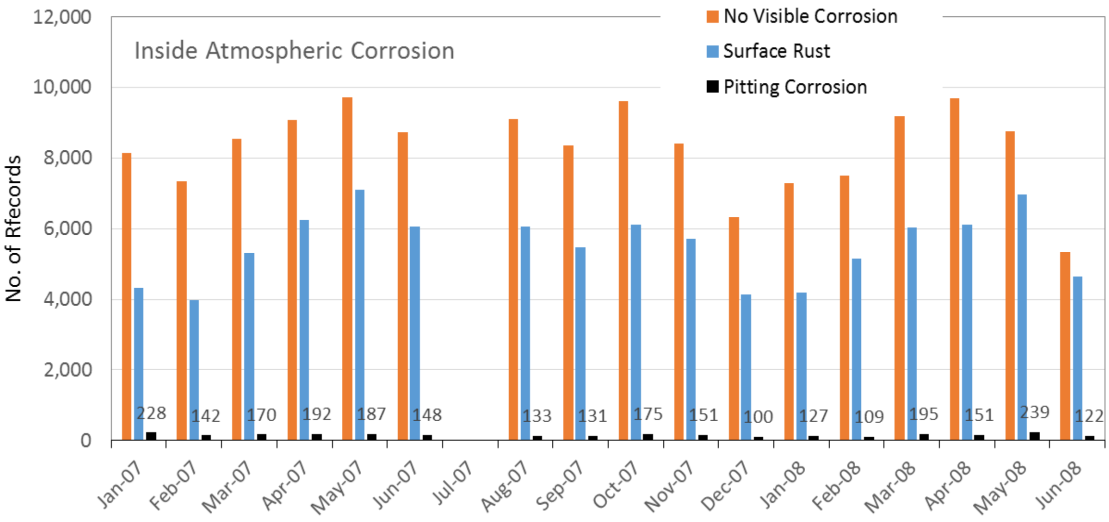
The indoor corrosion records (i.e., Inside Corr. Investigated in Figure 27) were categorized according to their condition and the repair job performed as follows:

1. Deep Pitting – repaired,
2. Pitting corrosion – referred to others for repair or replacement
3. Surface Rust, and
4. No Visible Corrosion

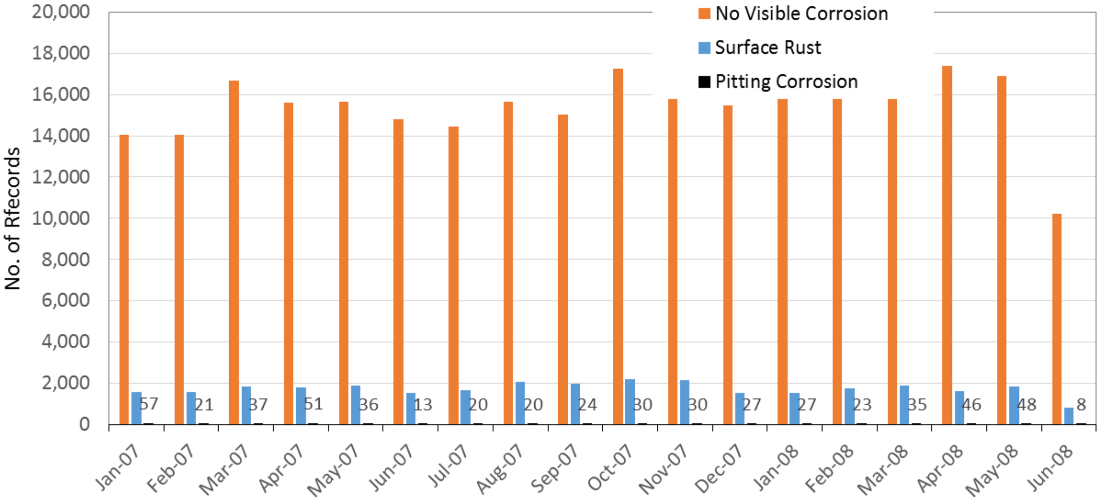
These indoor corrosion categories are shown in Figure 28 (a) to (c) for the three areas of New England (NE), New York City (NYC), and Long Island (LI). The figures show the monthly reports of the NE and NYC records, while the LI records are plotted for every 6 months. The results show following:

- The number of indoor locations with pitting corrosions (i.e., categories 1 and 2) were very small. An average of 1% of the atmospheric corrosion inspections in NE and LI had pitting corrosion which required repair or referring for further actions. The ratio is much lower (0.18%) in NYC.
- The remaining portion of the indoor corrosion inspection records (99%) had either no-visible corrosion or surface rust that was cleaned by brush.

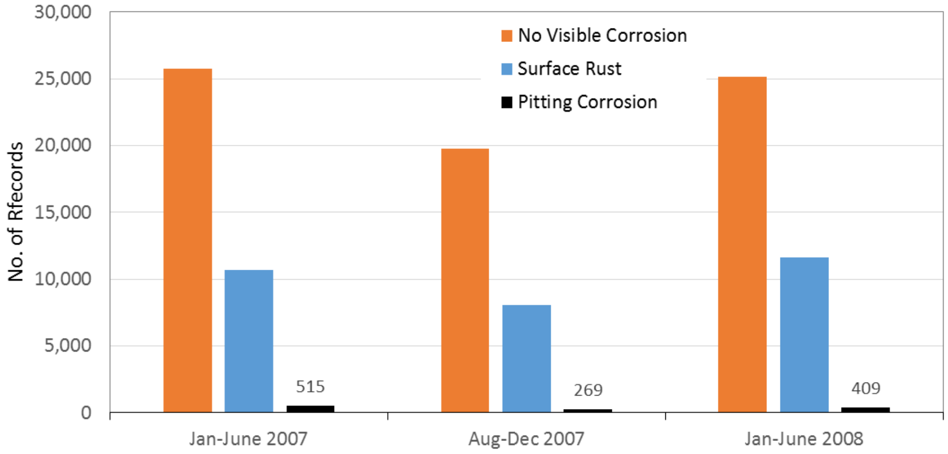
Further investigation of the pitting corrosion category is shown in Figure 29. The figures show the repaired and referred pitting corrosions in each of the study areas and they shows much smaller ratios of pitting corrosion records. For example, about 4% of all the pitting corrosion in NYC required repair by the utility crew.



(a) New England work records

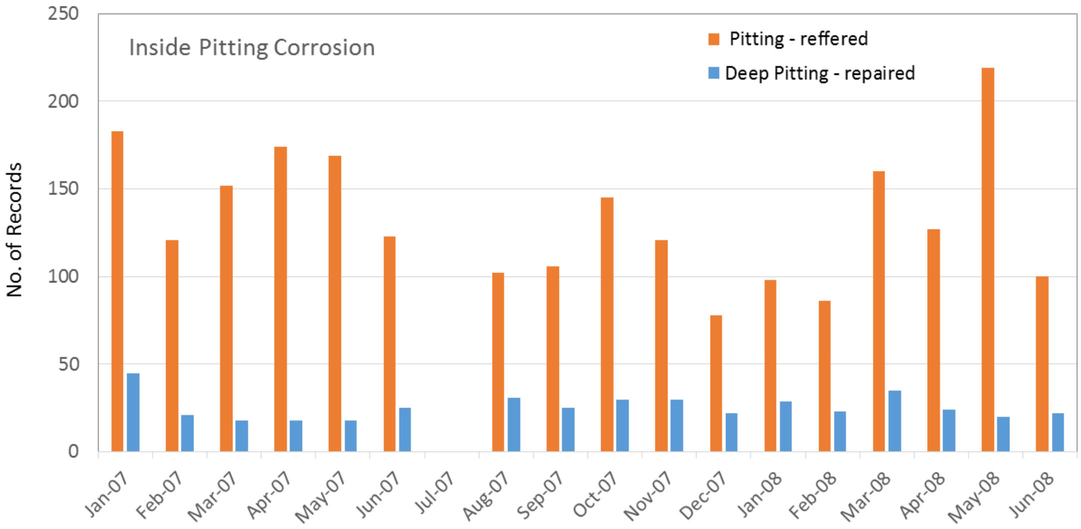


(b) New York City work records

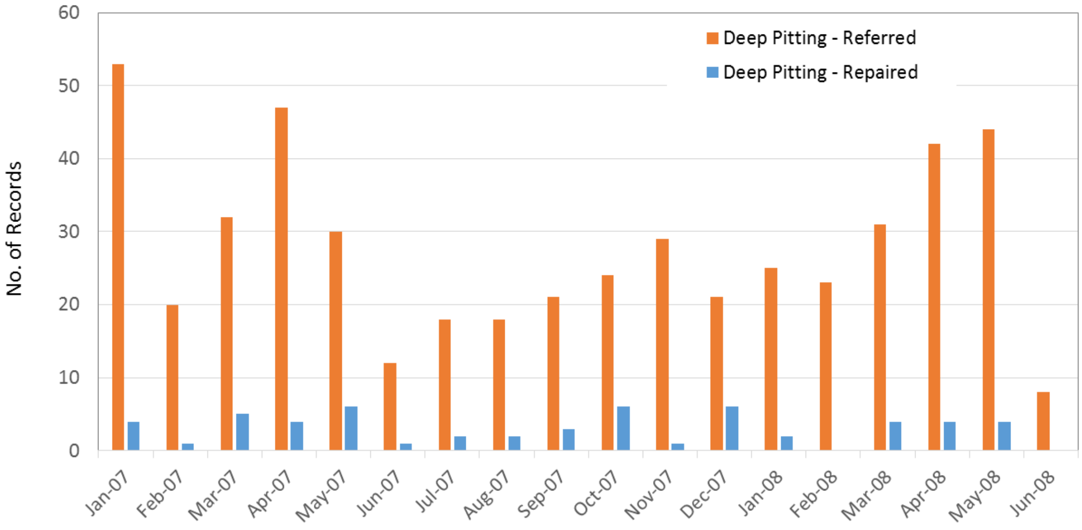


(c) Long Island work records

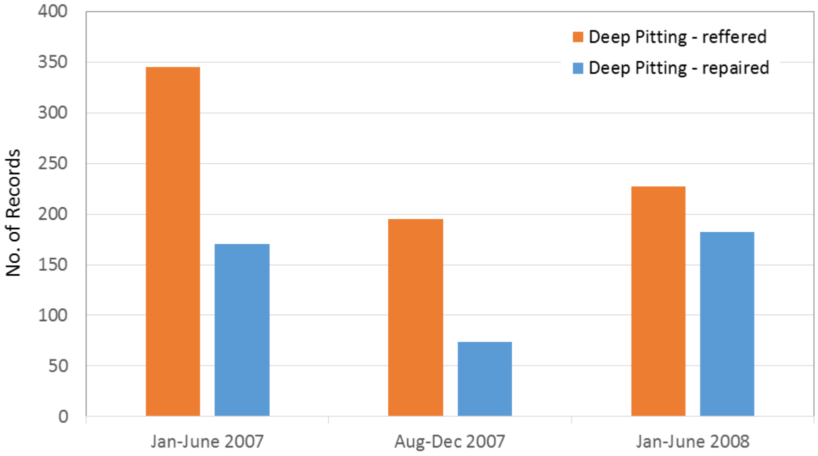
Figure 28. Records of indoor atmospheric corrosion categories [2007-2008]



(a) New England work records



(b) New York City work records



(c) Long Island work records

Figure 29. Records of indoor pitting corrosions [2007-2008]

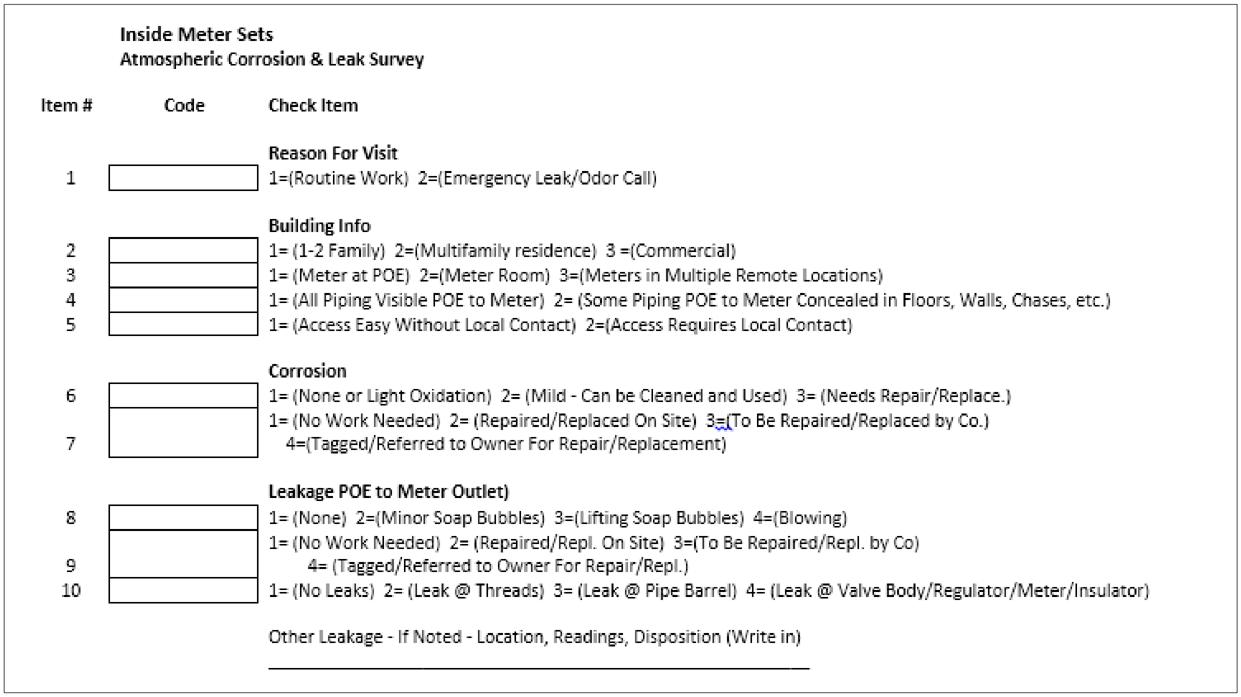
Analysis of Indoor Corrosion Factors

A recent survey (September, 2014) was performed by the natural gas utilities in New York State (National Grid, Consolidated Edison, NY State Electric & Gas, and National Fuel) to update and further enhance the investigation of the factors affecting indoor corrosion.

Survey Form

The survey was performed randomly using the data collection sheet shown in Table 16 during 1,050 routine utilities inspection, repair visits, and odor response calls in their service areas. The survey addressed both indoor atmospheric corrosion and leakage. This section investigates the corrosion records while the leak records are presented in Section 5 of this White Paper.

Table 16. Survey Form



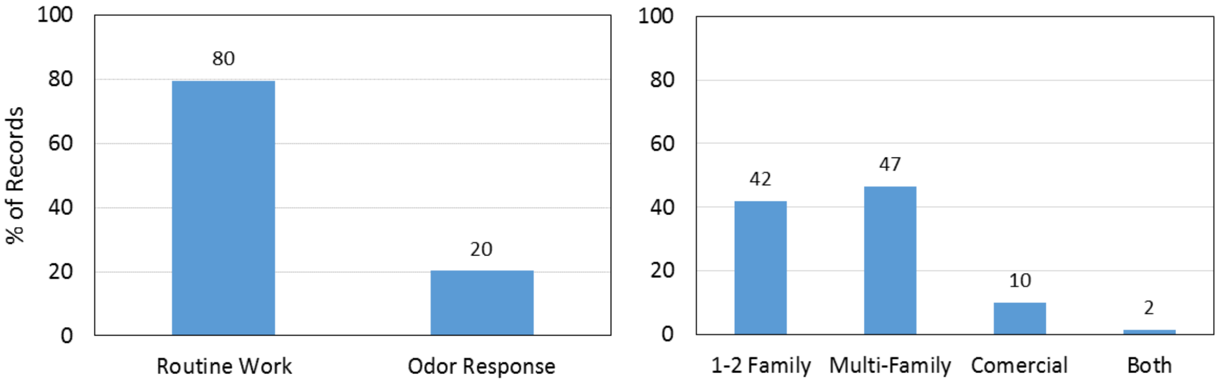
Inside Meter Sets
Atmospheric Corrosion & Leak Survey

Item #	Code	Check Item
		Reason For Visit
1		1=(Routine Work) 2=(Emergency Leak/Odor Call)
		Building Info
2		1= (1-2 Family) 2=(Multifamily residence) 3 =(Commercial)
3		1= (Meter at POE) 2=(Meter Room) 3=(Meters in Multiple Remote Locations)
4		1= (All Piping Visible POE to Meter) 2= (Some Piping POE to Meter Concealed in Floors, Walls, Chases, etc.)
5		1= (Access Easy Without Local Contact) 2=(Access Requires Local Contact)
		Corrosion
6		1= (None or Light Oxidation) 2= (Mild - Can be Cleaned and Used) 3= (Needs Repair/Replace.)
7		1= (No Work Needed) 2= (Repaired/Replaced On Site) 3=(To Be Repaired/Replaced by Co.) 4=(Tagged/Referred to Owner For Repair/Replacement)
		Leakage POE to Meter Outlet)
8		1= (None) 2=(Minor Soap Bubbles) 3=(Lifting Soap Bubbles) 4=(Blowing)
9		1= (No Work Needed) 2= (Repaired/Repl. On Site) 3=(To Be Repaired/Repl. by Co) 4= (Tagged/Referred to Owner For Repair/Repl.)
10		1= (No Leaks) 2= (Leak @ Threads) 3= (Leak @ Pipe Barrel) 4= (Leak @ Valve Body/Regulator/Meter/Insulator)
		Other Leakage - If Noted - Location, Readings, Disposition (Write in) ____

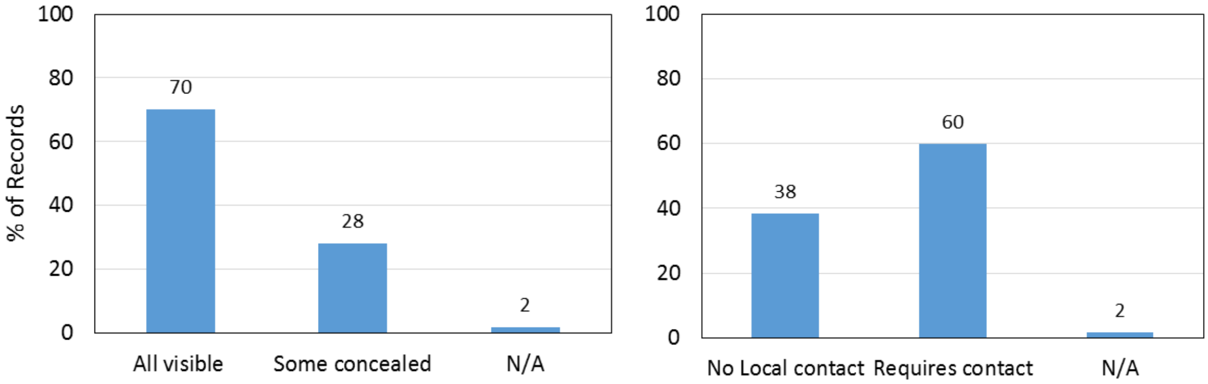
Reason for Survey and Building Information

The survey addressed several factors which were not present in the corrosion inspection records in the earlier sections of this chapter; notably the type of the building (commercial vs. residential), visibility of the piping system, and accessibility to the meter sets. The results of the survey are shown in Figure 30(a) to (f). The results show:

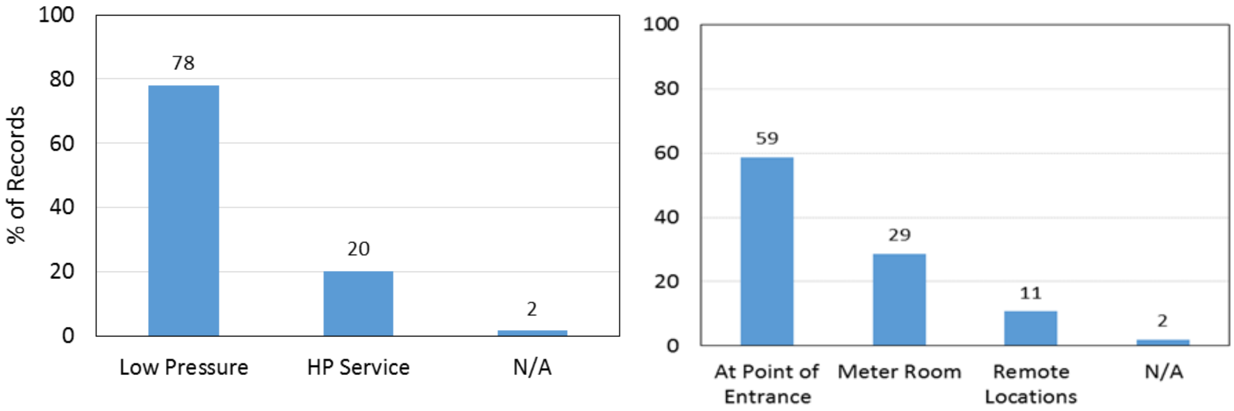
- Most of the inspection and repair records were performed during routine inspection work (80%).
- Most of the indoor inspections were in single and multi-family residential buildings (89%) and about 60% of the indoor inspections required prior local contact.
- Most of the indoor piping systems were low pressure (78%).



(a) Inspection Reason **(b) Building Type**



(c) Piping Visibility **(d) Service Access**



(e) Pipe Pressure **(f) Meter Location**

Figure 30. Results of the indoor corrosion inspection survey

Corrosion Indications

The corrosion indications of these records were categorized in a similar fashion to the earlier investigations and are shown in Figure 31.

The results show that most of the inspections (98%) had no-corrosion to mild surface cleaning with brush. A low record of 1% had corrosions which required repair or replacement. This percentage is similar to the ones in the studies presented in the earlier parts of this Section.

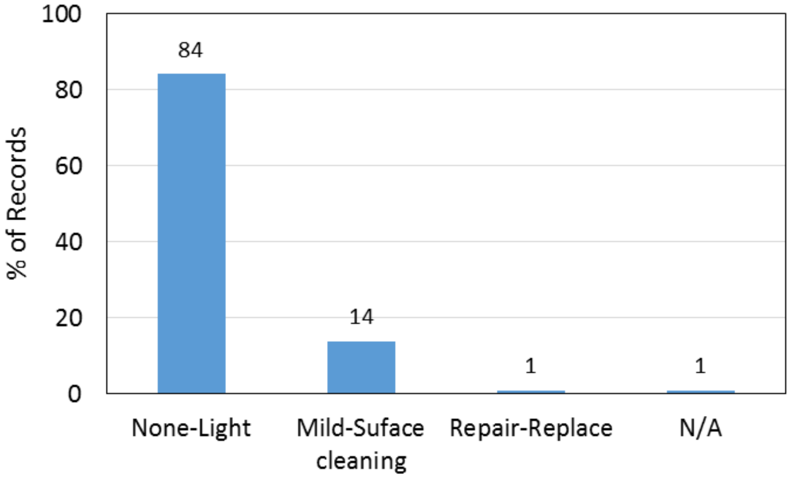


Figure 31. Corrosion records in the utilities inspection forms

Analysis of Characteristics and Locations of the Records (1% of Total) with Significant Indoor Corrosion

Figure 32(a) and (b) show the percentages of building types and meter locations where corrosions were recorded, respectively.

Most of the corrosions (70%) were found in multi-family buildings than in 1-2 family houses and commercial buildings. Corrosions were higher (60%) in meters at the point-of-entrance locations than indoor meter rooms.

It should be noted that the survey form in Table 16 did not further identify the location of the corrosion to investigate the condition of pipe at the wall penetration point. However, earlier investigations on atmospherics corrosion inspections [27] have shown that wall penetrations are potential locations needing corrosion investigation.

Figure 33 shows that most of the corrosion was in low pressure lines and in buildings which required prior local contact. However, these two factors characterize most of the service line system as shown in Figure 30.

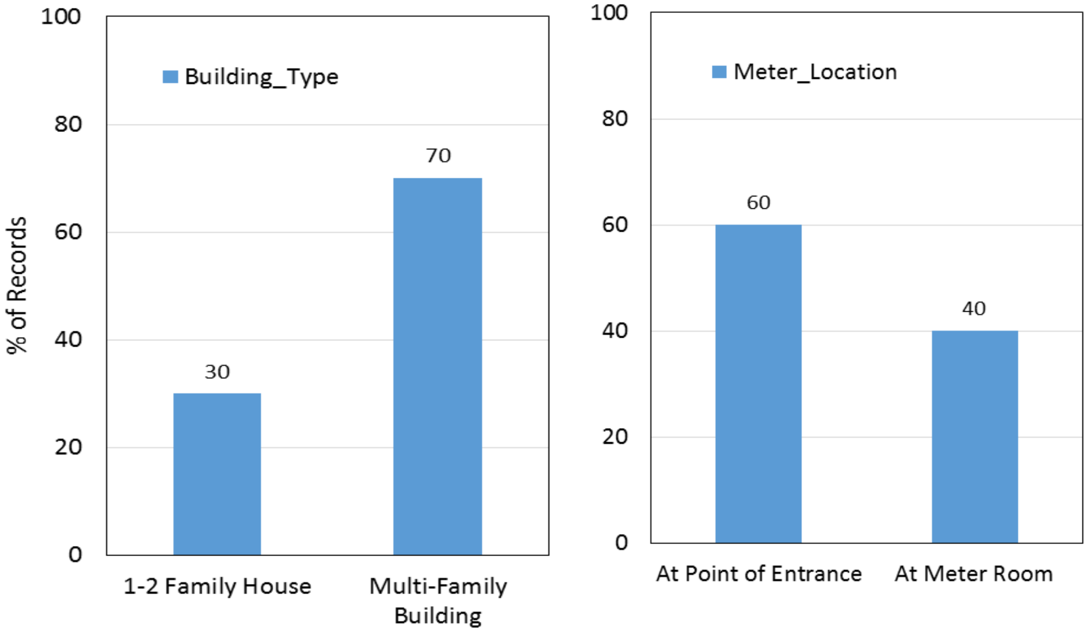


Figure 32. Corrosion in various building types and meter locations

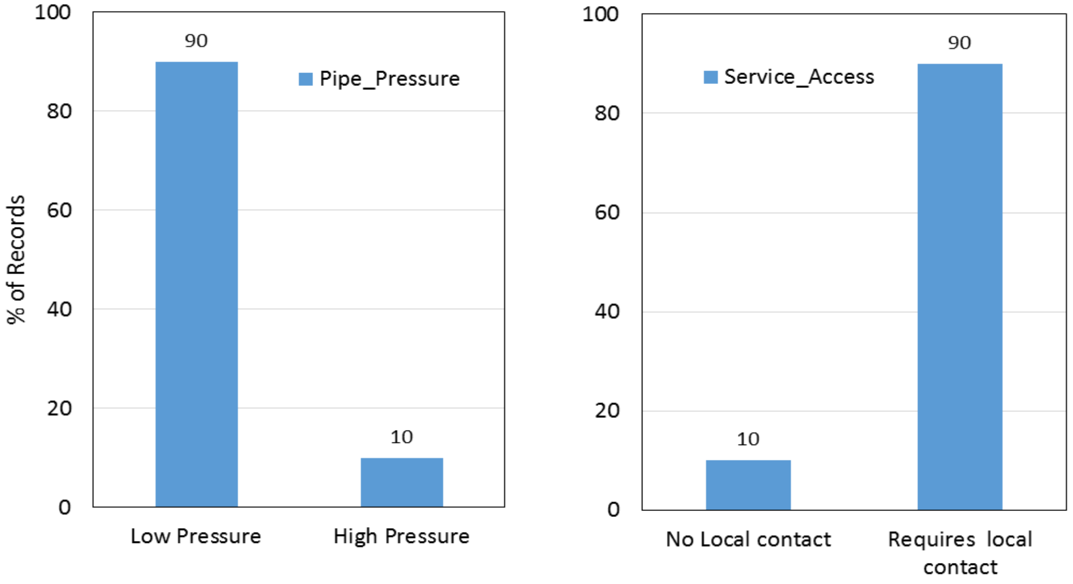


Figure 33. Pipe pressure and accessibility in records with corrosion

The sample size of the survey data was sufficiently large (1,050 records) to integrate the results in a theoretical estimation of the likelihood of corrosion due to the occurrences of certain independent parameters.

The results were integrated to estimate the likelihood of corrosions due to the occurrences of the above parameters. The process utilized the conditional probability approach to link the likelihoods of certain events to the occurrence of other ones. For instance, the analysis may provide the probabilities of corrosion in commercial versus residential buildings or at high and low pressure service lines.

The following equation illustrates the application of the conditional probability for the estimation of the probabilities of leaks in low pressure systems $P\ (LP, Corr)$:

$$P\ (LP, Corr) = P(Corr)x\ P(LP|Corr)$$

Where, $P(Corr)$ = Un-conditional probability that corrosion existed in the system. It is obtained from Figure 31 and equals 2% (0.02),

$P(LP|Corr)$ = Conditional probability of having a low pressure system with corrosion. It is obtained from the distribution of the pipe pressure in the records with corrosion (Figure 33) and equals 90% (0.90).

Substituting in the above equation results in $P\ (LP, Corr)$ = 0.02 x 0.90 = 0.018

This value is the likelihood of having a corrosion indication in a low pressure system, based on the data from the surveyed population. A graphical representation of the probabilities of corrosion for the high and low pressure systems is illustrated in a 'decision tree' approach in Figure 34.

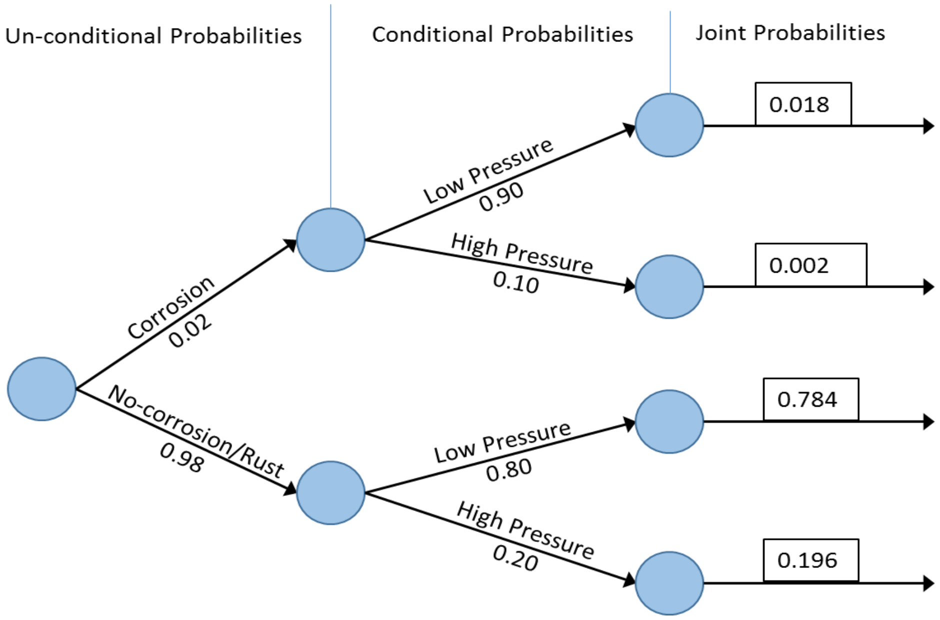


Figure 34. Decision tree representation of corrosion based on system pressure

A similar approach was used to construct a decision tree to estimate the probabilities of corrosion with respect to the various locations of the meter set. The results of this analysis are shown in Figure 35. This approach can be utilized to establish the likelihoods of corrosions based on the various site conditions for implementation in the corrosion risk analysis.

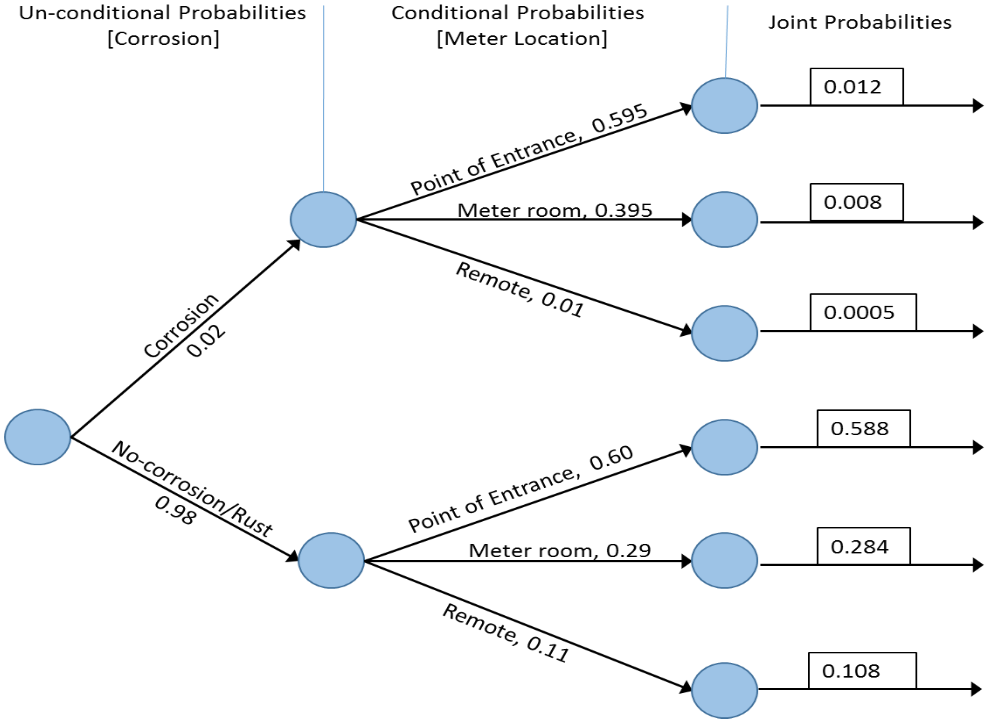


Figure 35. Decision tree representation of corrosion based on meter location

Key Findings from the Operator Corrosion Survey Data

The above sections reviewed utilities records of atmospheric corrosion and investigated the factors which influence the occurrence of indoor corrosion. The following summarizes the findings in this Section:

1. Most of the indoor inspection records had mild surface rust or no indications of corrosion. A minimum number of records (1%) had corrosion indications which prompted immediate or scheduled repairs.
2. Foundation type and the presence of sleeves or applied coatings were not significant terms to affect either the pipe or the meter piping corrosion conditions.
3. Pipe age, percentage of humidity, and pipe material type (i.e., bare vs. coated steel pipes) were significant parameters affecting indoor pipe corrosion condition. However, when it comes to the meter piping system, age and humidity were not significant terms affecting corrosion.

4. Investigation of corrosion is routinely performed during utilities work indoor buildings. More than 80% of the utilities work records in NY and MA included reporting corrosion condition, regardless to the type of job performed on site. The other 20% included jobs performed in other parts of the house or at locations with no access to the pipe.
5. The number of locations with pitting corrosions were very small. An average of 1% of the atmospheric corrosion inspections in NE and LI had pitting corrosion which required repair or referring for further actions. The ratio was much lower (0.18%) in NYC.
6. The characteristics and locations of the records with significant corrosion (i.e., requiring repair) were analyzed. Most of these corrosions (70%) were in multi-family buildings. About 90% of the corrosion indications were in low-pressure systems, and about 60% were at the point-of-entrance locations.
7. The records with significant corrosion were implemented in a conditional probability approach to estimate the likelihood of corrosions due to the various site conditions. Examples of these probabilities were plotted in a 'decision tree' diagram and it can be used to rank the risk parameters associated with occurrence of corrosion.

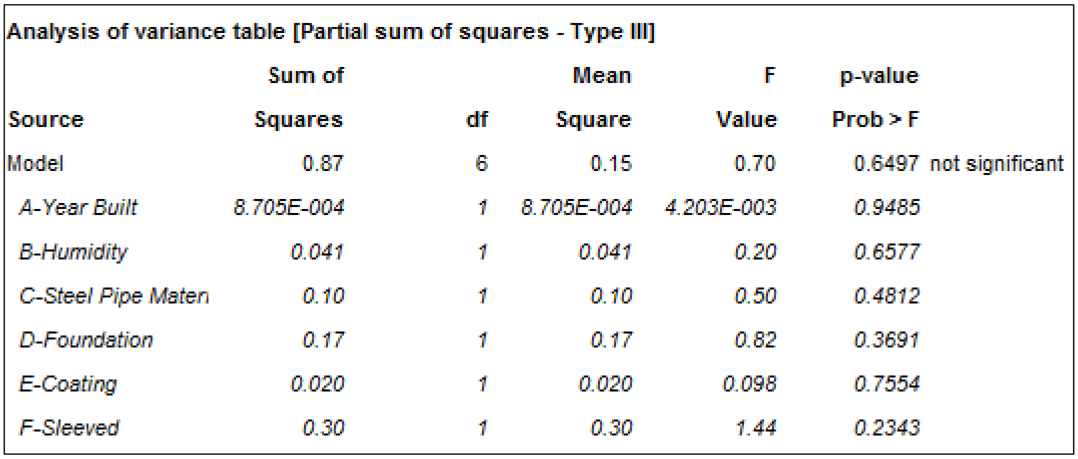
Parametric Study on Factors Affecting Leak

A parametric study of the historical records of a New York LDC (2007) was performed on inside meter-sets to evaluate the variables affecting the prediction of leakage.

The recorded parameters are listed in Table 13 and the distributions of these parameters are shown in Figure 19 to Figure 24. The correlations of these parameters with *corrosion* was presented in Chapter 4 and this section presents their correlation with *leaks*.

The data was analyzed using the Analysis of Variance (ANOVA) of the Design-Expert® Software program. Table 17 shows the results of the Analysis of Variance (ANOVA) on the leak response surface. The results show high p-values above 0.05; indicating that there is no strong relationship between the reported leaks and these parameters to construct a meaningful predictive model.

Table 17. ANOVA for Response Parameters on Leaks (Linear Model)



Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	0.87	6	0.15	0.70	0.6497	not significant
A-Year Built	*8.705E-004*	*1*	*8.705E-004*	*4.203E-003*	*0.9485*	
B-Humidity	*0.041*	*1*	*0.041*	*0.20*	*0.6577*	
C-Steel Pipe Materi	*0.10*	*1*	*0.10*	*0.50*	*0.4812*	
D-Foundation	*0.17*	*1*	*0.17*	*0.82*	*0.3691*	
E-Coating	*0.020*	*1*	*0.020*	*0.098*	*0.7554*	
F-Sleeved	*0.30*	*1*	*0.30*	*1.44*	*0.2343*	

The ANOVA analysis on corrosion in Section 4 showed that pipe age, humidity, and pipe material type were significant parameters which affected corrosion. However, none of these parameters were significant as related to leaks; indicating that these two responses are independent. This is mainly due to having noteworthy leak records at connections and threaded joints where corrosion was not present.

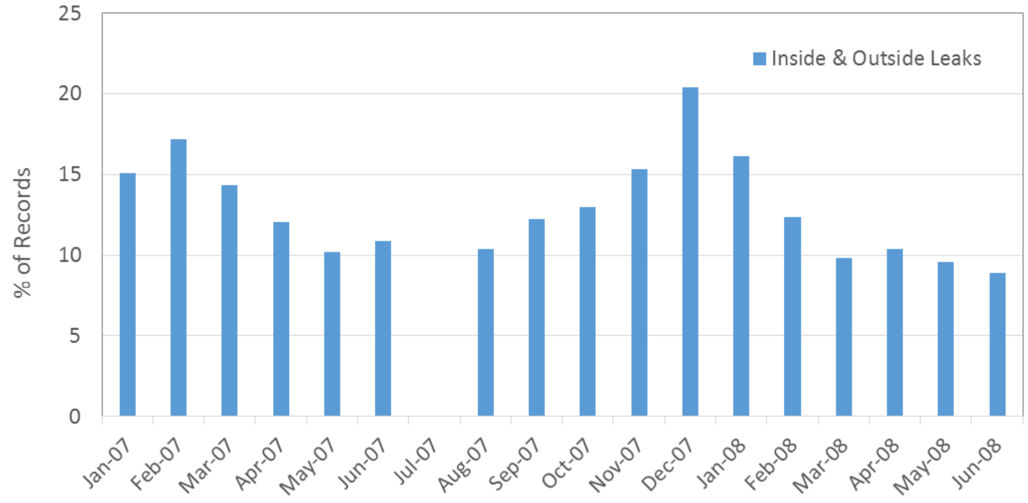
Investigation of Utilities Records of Leaks

The utility repair records in the States of MA and NY were investigated for the period from 2007 to 2008 to evaluate the occurrences of indoor with leaks.

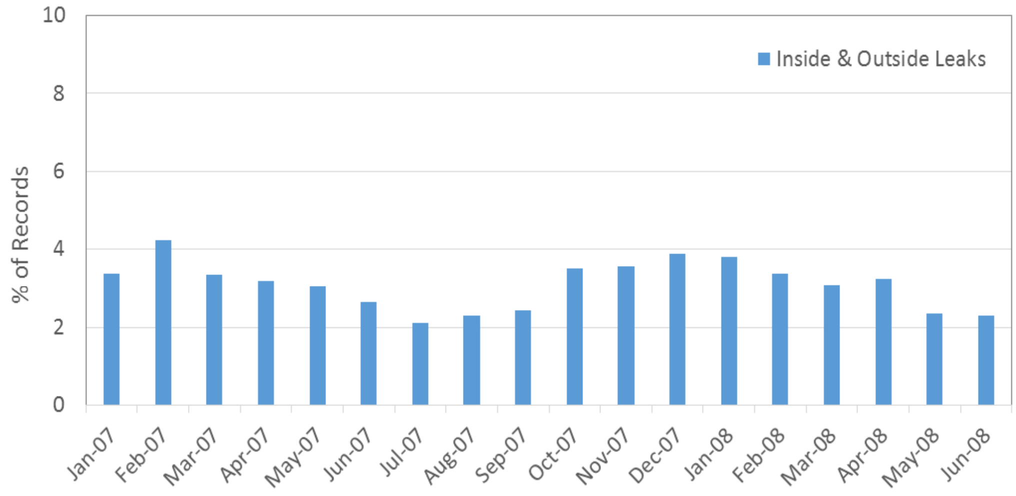
The repair records covered both indoor and outdoor routine utilities work and they included a wide range of service work (e.g., changing meters and regulators, locking and unlocking services, repair and replace valves and regulators, and repair leaks).

The indoor and outdoor leak repairs are shown in Figure 36 (a) and (b) as percentages of the monthly total jobs in both NE and NY LDC records, respectively.

Out of total leaks in the figures, the percentages of inside leaks are shown in Figure 37 for the NE and NY LDC.

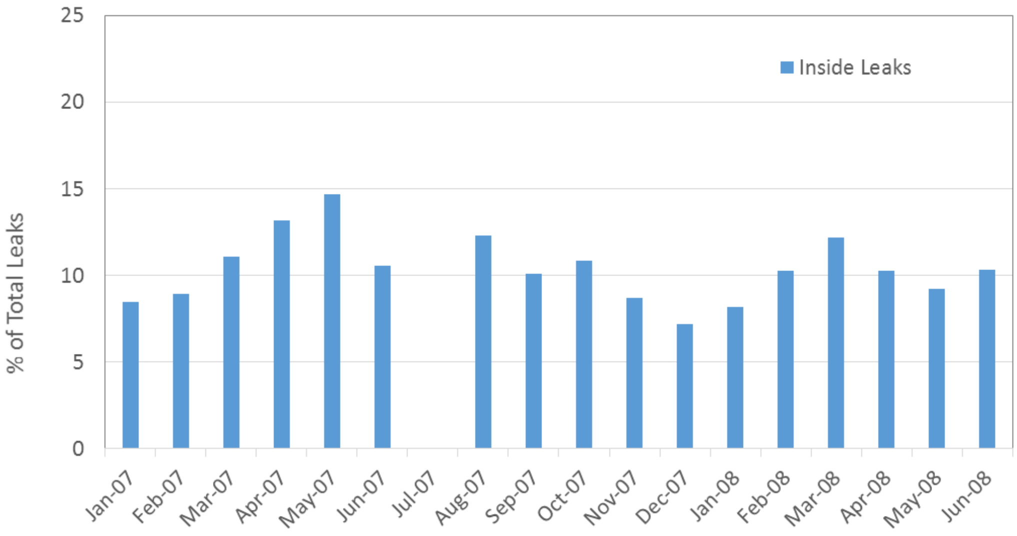


(a) New England work Records

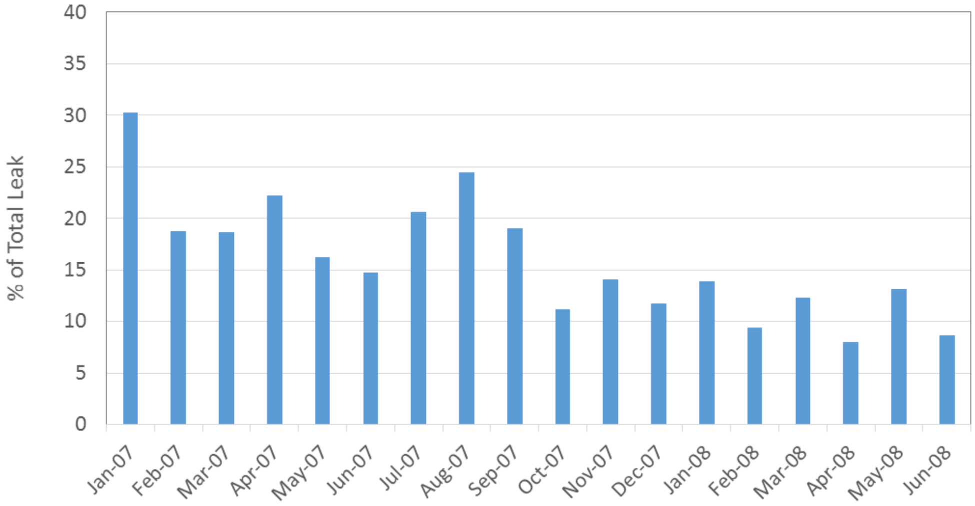


(b) New York City Work Records

Figure 36. Percentages of Indoor and outdoor leaks in all job records



(a) New England work Records



(b) New York City Work Records

Figure 37. Indoor Leak records as percentages of the total leaks

The results of the above figures can be summarized as follows:

- Total leaks (i.e., indoor and outdoor) records constituted an average of 10% of the total work jobs in MA and NY LDC repair records. The percentage of total leaks in NY was lower and was about 4%.
- Records where inside leaks were investigated averaged about 12% of the total leaks in the NY LDC records.
- The above percentages shows that inside leaks are about 0.6% of the total work in the NY LDC records.

Analysis of Inside Leak Factors

The results of the survey performed in 2014 by the gas utilities in the State of New York were analyzed to investigate the factors which affect indoor leaks.

The survey was performed randomly during 1,050 routine inspections and repairs by the utilities. The survey used the data collection sheet shown Table 17. This section investigates the indoor *leak* records while the *corrosion* records are presented in Section 4 of this White Paper.

The survey investigated the levels of leaks as identified during the routine utility work as shown in Figure 38. The results show:

- About 90% of the surveyed sites had no leak indications.
- About 5% had leak indications. The remaining 5% of the records had no entries to identify the leak indications.
- Most of the leak indications were identified as minor soap-bubble leaks (4.1% out of the 5% leak indications.)
- Significant blowing leaks were about 0.1% of the total repair records.

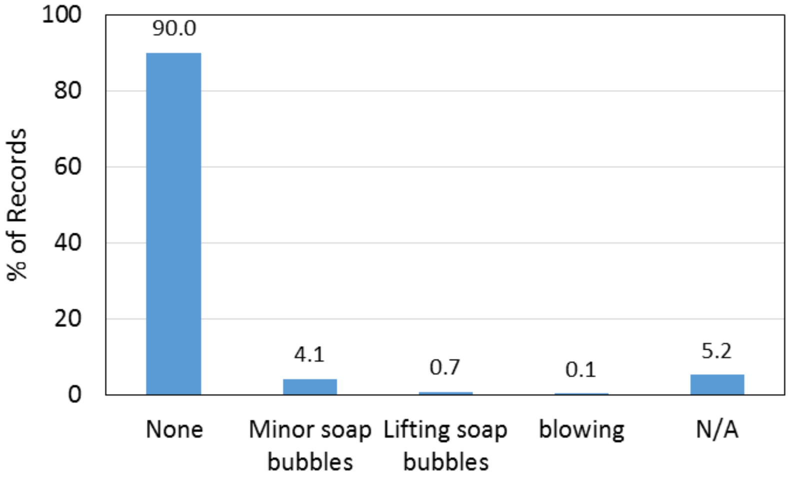
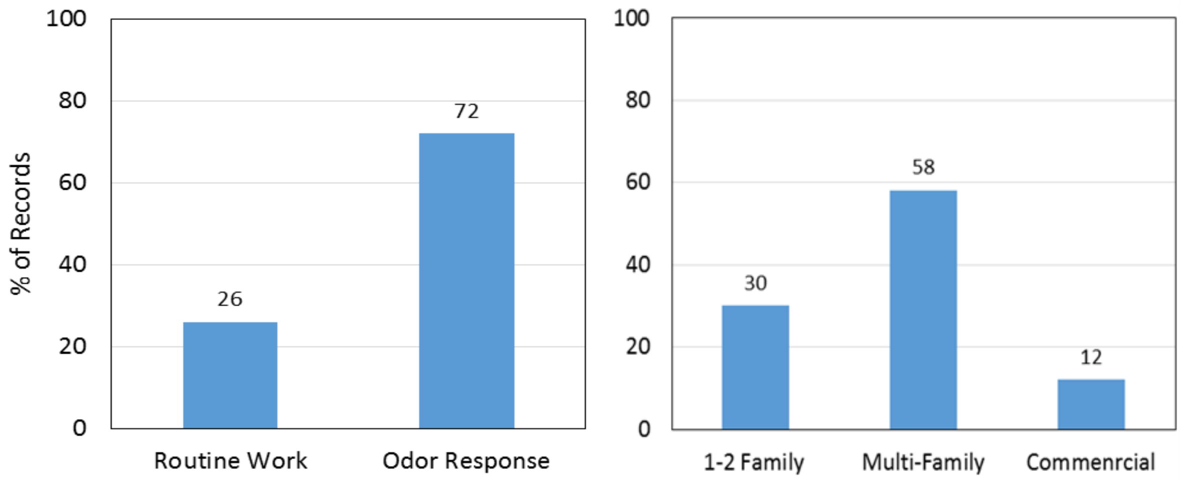
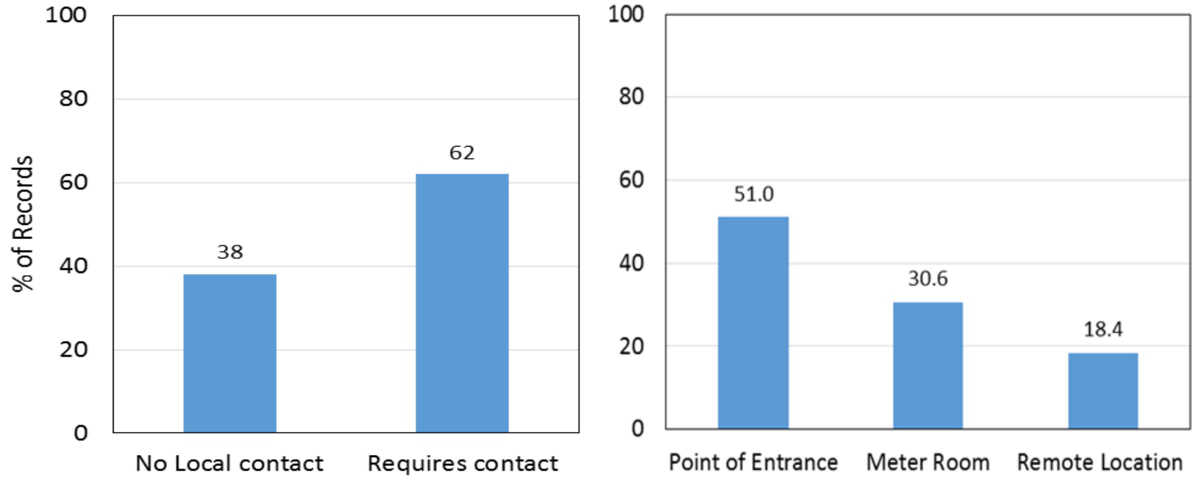


Figure 38. Results of indoor leak survey

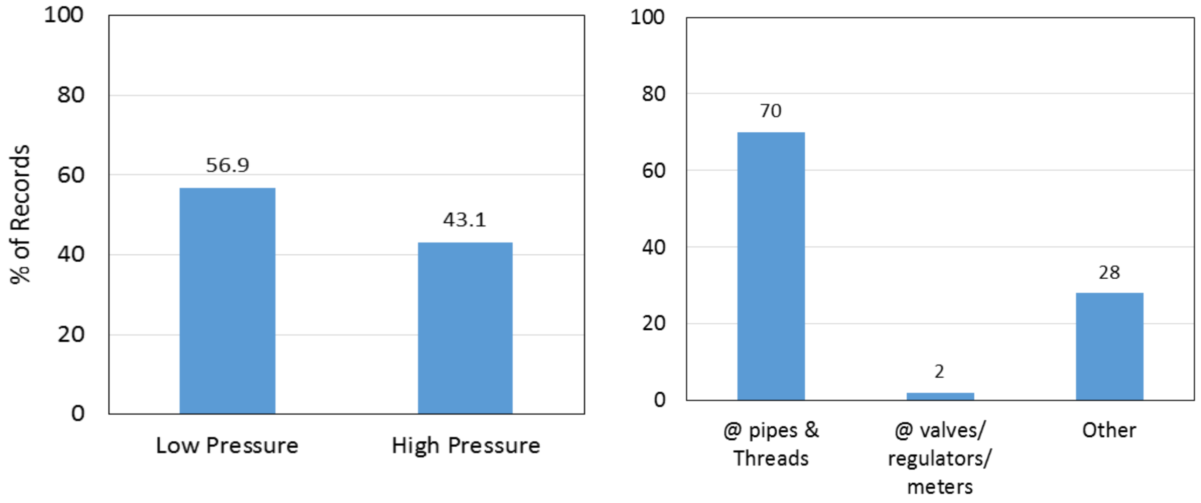
The leak sites were characterized in a similar fashion to the corrosion records in the previous section and are shown in Figure 39.



(a) Inspection Reason **(b) Building Type**



(c) Service Access **(d) Meter Location**



(e) Pipe Pressure **(f) Leak Location**

Figure 39. Characteristics of the leak sites

The characteristics of the leaking sites in the figure can be compared to the whole population of the inspections (shown in Figure 28) as follows:

- Leaks were mostly identified from odor responses (72%); this is in contrast to the corrosion indications which were mostly identified from routine inspection work.
- The other characteristics (e.g., building type and meter locations) are similar to the population distribution shown in Figure 28.
- Most of the leaks were at the pipe and threads. A small percentage of 2% was at the meter and regulator piping system.

The results were integrated to estimate the likelihood of leaks due to the occurrences of the above parameters. The process was similar to the one used in Section 4 and it utilized the conditional probability approach to link the likelihoods of leaks to the occurrence of these parameters.

For example, the conditional probability equation for the estimation of leaks in low pressure systems *P (LP, Leak) is:*

$$P\ (LP, Leak) = P(Leak) x\ P(LP|Leak)$$

Where, $P(Leak)$ = Un-conditional probability that a leak occurred in the system (0.05),
$P(LP|Leak)$ = Conditional probability of having the low pressure system when leak exists. It is obtained from Figure 39 and equals 56.9% (0.569).

Substituting in the above equation results in $P\ (LP, Leak)$ = 0.05 x 0.569 = 0.028

This value is the likelihood of having a leak in a low pressure system, based on the data from the surveyed population. A graphical representation of the probabilities of leaks for the high (distribution) and low (utilization) pressure systems is illustrated in a ‘decision tree’ approach in Figure 40.

The results in the figure show slightly higher probability of leaks in the low pressure lines (0.028) than the high pressure ones. It should be noted that the low pressure system constituted about 78% of the population in the survey as shown in Figure 30.

A similar approach was used to construct a decision tree to estimate the probabilities of leaks in 1-2 family, multi-family, and commercial buildings. The results in Figure 41 show that the occurrence of leak in the multi-family buildings (0.029) is almost twice that of the 1-2 family houses. This ratio is significant, given that the percentage of the multi-family buildings in the records is almost equal to that of the 1-2 family houses (Figure 30).

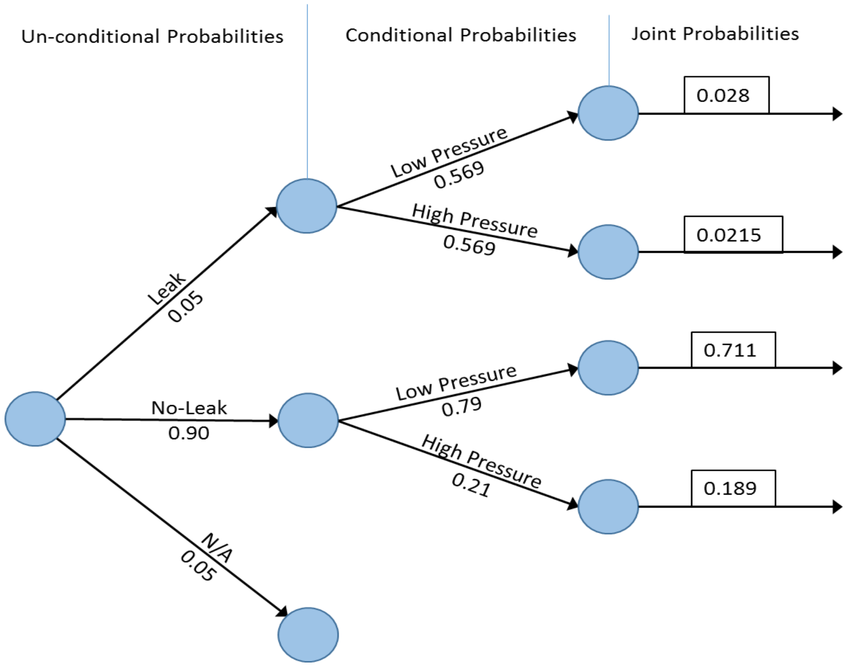


Figure 40. Decision tree representation of inside leak occurrences based on system pressure

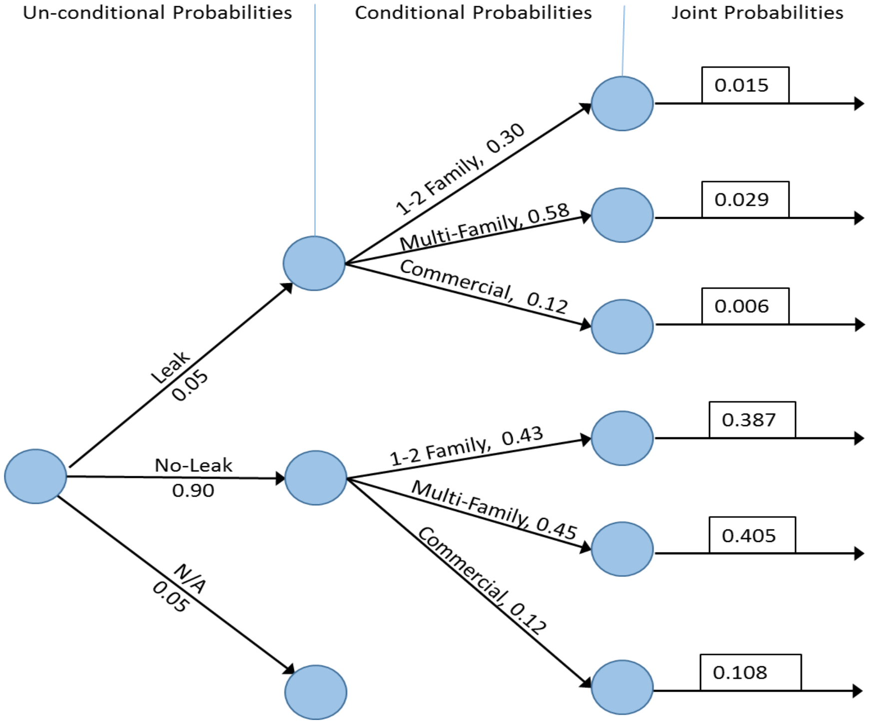


Figure 41. Decision tree of inside leak occurrences based on building type

Key Findings from the Operator Leak Survey Data

The following summary presents the main findings of the review of the utilities leak records:

- The indoor leak records in NY State show that about 5% of the records had minor to medium indications from the soap bubble tests. About 0.1% of these records had a higher leak indication.
- Leaks were mostly identified from odor responses (72%); this is in contrast to the corrosion indications which were mostly identified from routine inspection work (80%).
- The effect of pipe age, humidity, meter locations, and pipe material type were investigated on leak records. None of these parameters was a significant term affecting the leak records.
- Leak records did not correlate to corrosion indications. Most of the leaks were at the pipe and threaded joints while a small percentage (2%) was at the meter and regulator piping system.
- The leak records were implemented in a conditional probability approach to estimate the likelihood of leaks due to site conditions. Decision tree diagrams were plotted to illustrate the procedure. These probabilities can be used to rank the risk associated with the occurrence of leaks.

6. Risk-Based Considerations and Conclusions

Summary and Conclusions Related to Indoor Atmospheric Corrosion

The peer-reviewed literature search concluded that relative humidity, and its interaction with pollutants, are the main drivers for atmospheric corrosion. The variation in humidity and temperature are dramatically lower indoors than outdoors and when combined with the absolute lower humidity and pollutant levels, it results in lower corrosion rates for indoor steel and iron assets.

Quantitative, scientific and engineering data showed that indoor atmospheres result in an often significantly low corrosion rate than for outdoor atmospheres. Mean indoor corrosion rates are reported at 2-3 orders of magnitude (100 to 1,000 times) lower than outdoor rates. A seminal, multi-year indoor vs. outdoor corrosion rate study showed indoor corrosion of steel/iron to be a factor of 2,000 times lower than the outdoor corrosion rates. This study included New York, New Jersey, Los Angeles, Chicago, Texas, Indiana, and South Carolina. The published work collected concluded that the marked reduction in indoor iron corrosion is accounted for by both a reduction in high humidity occurrences and a reduction in pollutant levels.

Historical (2007-2008) NY LDC corrosion and leak surveys (outside and indoor) of meter-set populations were collected and analyzed. A statistical regression analysis concluded that the most significant parameter related to corrosion condition was relative humidity, just as the peer-reviewed literature concluded.

Pipe age had the next highest correlation. The number of indoor locations with pitting corrosion was very small. For example, in New England and Long Island, an average of 1% of the indoor inspections had corrosion conditions that required further action; the percentage in New York City was even lower at 0.18%.

Supplementing this data was a second set of data, recently completed in September of 2014, of four NY State LDCs with over 1,000 on site, indoor corrosion and meter set/piping surveys. The results also showed that 98% of the inspections had no corrosion or mild surface rust that was cleaned with a brush. Only 1% of the corrosion required repair or replacement.

Based on decades of peer-reviewed field testing and analysis, coupled with 2007, 2008, and 2014 in-field surveys by NY State operators of thousands of service sets, the indoor corrosion rate is typically 100-1,000's of time lower than the outdoor rates. Furthermore, the occurrence of noteworthy indoor atmospheric corrosion is encountered less than 1% of the time, sometimes significantly less than 1%.

A practical example of pipe corrosion using the very conservative 99% upper confidence levels for corrosion rates, showed that it would take about 100 times longer to corrode through 25% of a ¾ inch diameter iron pipe wall indoors as it would outdoors. It also shows that the buried conditions would corrode the same distance in about half the time of outdoor. It is evident that different, extended inspection intervals are warranted and appropriate for indoor environments vs. outdoor environments.

The combined findings of this paper suggest that the intervals for indoor corrosion surveys can defensibly be set to longer periodicities as compared to outdoor surveys of similar meter sets and piping. This would facilitate optimization of Operator resources to be focused on more aggressive corrosive environments, thereby lowering composite risk and increasing overall safety; all fundamental principles of distribution integrity management.

Summary and Conclusions Related to Indoor Leak Surveys

The indoor leak records in NY State show that about 5% of the records had minor to medium indications from the soap bubble tests. About 0.1% of these records had a higher leak indication. Leaks were mostly identified from emergency odor calls (72%); this is in contrast to the corrosion indications which were mostly identified from routine inspection work (80%).

The effect of pipe age, humidity, meter locations, and pipe material type were investigated on leak records. None of these parameters was a significant term affecting the leak records. Leak records did not correlate to corrosion indications. Most of the leaks were in the pipe and threaded connections. A small percentage (2%) was at the meter and regulator piping system.

The leak records were implemented in a conditional probability approach to estimate the likelihood of leaks due to site conditions. Decision tree diagrams were plotted to illustrate the procedure. These probabilities can be used to rank the risk associated with the occurrence of leaks.

A set of risk-based considerations for categorizing the indoor atmospheric service and indoor leak survey environments, to assist with the development of engineering based indoor corrosion and leak survey intervals, are presented below.

Risk-Based Considerations for Indoor Atmospheric Corrosion and Related Surveys

Based on the information developed in this study, the following could be considerations as part of a risk-based approach to establishing appropriate corrosion and leak survey intervals for indoor locations.

Each utility has its own macro and micro environments based on geographic location and concentration of urban, industrial, rural, and coastal/marine operations. Therefore these considerations should be adjusted and applied as appropriate. These risk factors should be incorporated into an Operators DIMP Plan when devising appropriate inspection frequencies.

However, the considerations below were shown to be true across the broad categories of environments and regions and are generally listed in the order of importance for consideration.

1. **Relative Humidity.** Relative humidity is the largest driver for corrosion rates at indoor locations. This could be a category for inspection class.
    a. Locations indoor and aboveground (above grade) and air conditioned might be part of the 'lowest likelihood' for corrosion category, followed by those indoor and aboveground and

    not air conditioned, and finally by those below grade (e.g., in a basement) and not air conditioned; although even these situations have a significantly reduced corrosion rate to any outdoor locations, due to the moderating effect of the indoor environment and the heat sink/source of the ground.

   b. Consistent relative humidity of greater than 70% to 80% could represent a consideration point for a category change toward more likely for corrosion.
   c. In total, the indoor atmospheric rate of corrosion is up to three orders of magnitudes lower than outdoor atmospheric corrosion rates. This applies across Urban, Rural, Industrial, and Marine/Coastal environments. This should be taken into consideration when balancing needs for both outdoor and indoor atmospheric corrosion surveys as part of distribution integrity management programs.
2. **Pollutants.** Typical levels for outdoor and indoor pollutants are provided in the white paper and its references.
   a. Areas with high Sulfur Dioxide (SO_2) pollution levels could be considered more corrosive than those with lower levels.
   b. The areas that have *both* the high relative humidity *and* substantial levels of SO_2 and/or particulate/mist chlorides (e.g., from coastal regions) would be the most corrosive to iron and steel components. For most indoor locations these situations are very rare.
3. **Age of System.** Older piping systems had more occurrences of pitting as a percentage of all systems and should be considered in a category that could have increased presence of corrosion pitting. This is simply due to the time in service, allowing for increased wetting time, pollutant interaction, and therefore metal corrosion.
4. **Solid matter, soot, and other deposits.** These deposits can increase atmospheric corrosion rates. Impurities from emissions like CO_2 and CO are adsorbed in dust particles, and when combined with moisture provide micro-corrosion cells. These locations could be considered as a category for additional inspection considerations.
5. **Location.** There was a moderate increase in corrosion present at point-of-entry locations versus indoor space.
6. **Bilogarithmic Corrosion Law.** The validated bilogarithmic law can be used by operators to help establish appropriate indoor atmospheric corrosion levels. By consulting historical and new data, the constants in law can be determined for each macro and/or micro environment class and then the relation can be used to predict metal loss rates.
7. **Use of Conditional Probabilities for Corrosion and Leak Surveys.** This paper used a conditional probability approach to estimate the likelihood of corrosion and leaks due to site and system conditions. Decision tree diagrams were plotted to illustrate the procedure. These probabilities can be used to rank the likelihood associated with the occurrence of corrosion and leaks for specific site and system conditions.

8. **Other Factors.**

   a. There are other factors that might be considered such as bare vs. coated piping, absolute temperature, etc.; but the literature, as well as historical and recent survey data, establishes that these are secondary to the items listed above.

   b. Each operator knows the service environment of their assets and should include secondary or tertiary considerations as appropriate.

   c. As environmental conditions change, or upset conditions like super storms, flooding, fire, and other occurrences happen, they should be figured into the assessment categories and intervals of an indoor inspection schedule as appropriate.

Categorical Approach to Appropriately Set and Refine Indoor Corrosion Survey Intervals

One possible, engineering-based approach to setting indoor inspection intervals would include a series of categories with shorter inspection intervals for higher risk or likelihood of corrosion situations and longer inspection intervals for the lower risk or likelihood of corrosion situations.

As was shown in Section 3 of the report, even using the very conservative 99% upper confidence level for indoor corrosion rates, the time to identical corrosion depths was 100 times longer than for outdoor corrosion rates and nearly two hundred times longer as for buried, uncoated and unprotected iron or steel. This would suggest that for the same level of risk tolerance between inspection intervals as for outdoor atmospheric corrosion that the indoor intervals could be markedly longer.

In addition to the use of the 99% upper confidence corrosion rate, one could set the typical interval to 15-20 years. Based on the information presented in this paper and the cited references, this would be quite conservative. Using the same rates as presented in Section 3, this would allow (with a 99% upper confidence level) for corrosion of less than 2% of the pipe wall, which is extremely low from an engineering design basis.

As atmospheres are noted to be more benign than the 99% upper confidence level, then these system components could be put into categories with longer times between intervals, say 20-25 years. Likewise as atmospheres or environments are noted to more corrosive, the system components could be shifted to a shorter interval between surveys, say 10-15 years.

The numbered, risk-based considerations presented above should be leveraged with ongoing, continuous feedback from surveys. The operator should incorporate ongoing data collection and feedback to refine the inspection interval categories, their length, and what components go into each category.

The content of this white paper provides information for every operator to draw upon when setting up suitable and robust risk-based inspection intervals as part of their distribution integrity management program. These results should be appropriately combined with operator-specific data and knowledge to form the basis for inspection intervals and the overall assessment program.

End of White Paper Body

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Leak Survey Equipment Considerations for NY Operations

Development of a Regulatory Conformance and Technology Applicability White Paper

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Prepared For
Northeast Gas Association (NGA)

GTI Contacts

Daniel Ersoy
M.Sc., CF.APMP, NACE CIP III
R&D Exec. Director, Energy Delivery
847-768-0663
daniel.ersoy@gastechnology.org

Karen Crippen
R&D Manager
847-768-0604
karen.crippen@gastechnology.org

Paul Armstrong
Director, Business Development
781-449-1141
paul.armstrong@gastechnology.org

Gas Technology Institute
1700 S. Mount Prospect Rd.
Des Plaines, Illinois60018
www.gastechnology.org

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Executive Summary

The New York State Public Service Commission (NYSPSC) adopted a new definition of a gas service line effective April 2, 2015 (Case 14-G-0357) to align New York's "service line definition" with the federal definition in 49 CFR Part 192. Prior to adopting this change, the definition of a service line in New York ended at the first fitting inside the front wall of a building for inside meter locations. The change in New York extends jurisdictional piping to the outlet of the gas meter even when the meter is located inside a building and the piping was installed and historically maintained by building owner or where required by statute, by the building owners licensed plumber. Accordingly, LDCs are now obligated to perform periodic leak surveys and visual atmospheric corrosion inspections in accordance with federal and state code requirements. In response, Commission staff recently issued a Straw Proposal requesting comments from LDCs to substantiate the use of Combustible Gas Indicators (CGI) with a minimum gas detection threshold of 0.1% gas in air (parts per thousand) for leak survey of inside service lines. This white paper lays out the technical justification and fit-for-purpose nature for the use of CGI technology as applied to inside leak surveys.

Instruments for leak surveys and leak pinpointing/investigations are mature technology that have been on the market for many years. The instruments incorporate different sensor types depending on the practical application of the equipment and site specific conditions. The most sensitive technologies are used for leak surveys of buried outdoor piping. Low sensitivity thresholds (ppmv) are required to compensate for a variety of environmental variables resulting in diluted gas concentrations outdoors and/or reaction with the soil and other subsurface variables effecting gas migration patterns. In contrast, sensitivity detection thresholds for instruments typically used for indoor leak investigations and surveys, where the survey environment is not affected by variables such as wind/soil diffusion and gas migration patterns, are greater than instruments used for outdoor surveys.

While it may seem counter intuitive, if the instrument threshold detection limit is too low (i.e., too sensitive), it may impede leak detection in the presence of a background combustible gas concentration at the parts per million level. The device may trigger a false alarm when the conditions are only slightly above background. Using leak survey equipment with a parts per million detection threshold for indoor piping may hinder an effective and efficient leak survey process.

One margin of safety calculation is a measurement of the difference between an instrument's detection threshold, and the Lower Explosive Limit (LEL) of methane in air (5% methane in air). If a CGI threshold detection value is 0.1% gas in air (one part per thousand), the difference between the threshold detection limit and the LEL value is 50 times. Margins of safety for engineering design range from 1.5 to 20 times, depending on the application. The 50 times margin of safety is at least 2½ times greater.

NY State regulation 16 NYCRR-255.3(a)(12) defines the leakage survey process. This definition goes beyond the current federal definition by specifying detection thresholds rather than stating that an appropriate, properly calibrated instrument be used. With the change of the NY State service line definition, and the inclusion of indoor piping as part of this definition, NY State should broaden their leak survey requirements to parallel current federal code and allow the use of technically substantiated leak survey equipment at appropriate detection thresholds for use in indoor environments.

CGI use is a long accepted past practice that has a proven track record of safety. NY LDC leak investigation practices prescribe the use of CGIs at the parts per thousand detection threshold to investigate potential indoor leak claims. LDC leak survey technicians and emergency response personnel are already equipped and trained in the use of a CGI for leak investigation of inside piping systems. Because indoor gas leaks are in a controlled and contained space they are less affected by external environmental variables, and result in a situation that does not require as sensitive an instrument and associated low detection threshold set point. A typical CGI has a 50 times margin of safety based on the LEL concentration of methane. CGIs should be considered fit-for-purpose for indoor leak surveys.

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Background

The New York State Public Service Commission (NYSPSC) adopted a new definition of a gas service line effective April 2, 2015 (Case 14-G-0357) to align New York's "service line definition" with the federal definition in 49 CFR Part 192. This new service line definition extends jurisdictional piping to the outlet of the gas meter even when the meter is located inside a building. This effectively broadens the inspection purview of piping under the jurisdiction of the LDC to include natural gas piping inside of buildings up to and through the outlet of the gas meter. Accordingly, LDCs are now obligated to perform periodic leak surveys in accordance with federal and state code requirements.

In order to help meet this requirement, Commission staff recently issued "*Straw Proposal for The Adoption of Gas Service Line Leakage Survey and Corrosion Inspection Requirements*" as part of Case 15-G-0244. This Straw Proposal is requesting comments from LDCs to substantiate the use of Combustible Gas Indicators (CGI) for leak survey of inside service lines.

New York State regulation 16 CRR-NY-255.3(a)(12) stipulates "Leakage survey means a systematic survey made for the purpose of locating leaks in a gas piping system using an approved instrument which continuously analyzes atmospheric samples near ground level and is capable of detecting the presence of gas in parts per million air." It is surmised from the "…near ground level …"and the "… detection … in parts per million air" language, and from the fact that historic NYS definition of a service line ended at the first fitting inside the building wall, that this section of the NYS code was intended to apply to leakage surveys of <u>below ground outdoor</u> natural gas piping systems vs. exposed indoor piping systems. The NY LDCs and the GTI study propose to utilize combustible gas indicators (CGIs) with a minimum gas detection threshold of 0.1% gas in air (parts per thousand) as a means to meet the new requirement for indoor surveys.

A review of the use of CGIs with a parts per thousand detection threshold (0.1% gas in air) as an applicable technology option for inside leak surveys is therefore desirable. This review lays out the technical justification for use of these CGI instruments with fit-for-purpose detection thresholds.

This white paper is intended to be a regulatory conformance and technology applicability study. The objective is to weigh all considerations, and assess the fit-for-purpose nature of the CGI technology as applied to inside leak surveys - all viewed through the lens of public safety.

(1) Current and Proposed Survey and Use Case Requirements

New York State regulation 16 CRR-NY-255.3(a)(12) stipulates "Leakage survey means a systematic survey made for the purpose of locating leaks in a gas piping system using an approved instrument which continuously analyzes atmospheric samples near ground level and is capable of detecting the presence of gas in parts per million air." This definition goes beyond the current federal definition and associated requirements by specifying detection thresholds rather than broadly defining an appropriate, properly calibrated instrument for purposes of detecting gas-in-air concentrations indicative of a pipeline leak.

The NYS code requirement for leak survey instrumentation is consistent with the historic NYS definition of a service line, which terminated at the outlet of the meter or the first fitting inside the building wall, whichever came first. The types of approved equipment at the parts per million detection level are appropriate and consistent with the survey requirements for outdoor buried piping systems. With the change of the NY State service line definition to align with the federal code and the inclusion of indoor piping as part of this definition, NY State should consider broadening their leak survey requirements to parallel current federal code in this regard and allow the use of technically substantiated leak survey equipment at appropriate detection thresholds for use in these indoor environments.

Outdoor leak surveys of buried piping are affected by a number of variables relative to leak surveys of indoor piping systems. Most notable is the contained environment and direct access to the indoor exposed piping in contrast to inaccessibility of buried piping, leak diffusion, atmospheric conditions, and soil interaction affecting gas leak migration patterns. These issues are expanded upon in Section 2 of this White Paper. As a result, the leak survey equipment for these two applications are frequently different in terms of sensor technology, device features and detection levels.

The application under consideration within this White Paper is leak survey of visibly accessible indoor piping systems. We specifically note the difference between the leak survey and leak investigation processes. Leak survey of indoor piping is the process of sampling the atmosphere for combustible gas in the vicinity of the exposed pipe and fittings up through the outlet of the meter. If combustible gas is detected, the leak investigation process begins and the piping and appurtenances are further examined along the path of the pipe where the leak source is pinpointed. For inside piping, the same equipment (CGI) is often used for *both* the initial leak survey *and* the pinpointing investigation.

(2) Differences between Conventional Outdoor Leak Survey Instruments and CGIs

Outdoor leak survey equipment used for leakage surveys of buried piping is different from combustible gas indicators used for pinpointing below ground leaks, indoor leakage surveys, and worker safety.

Some differences could include:

- sensor configuration
- sensitivity thresholds
- measurement units
- alarm set points
- calibration requirements
- gases that are detected
- procedures & patterns of use

Some equipment can serve a dual purpose. These are usually air quality combustible gas monitors that can be outfitted with a sampling wand and pump to serve as leak detectors in addition to their original purpose. A description of the sensor detection technologies is found in Appendix B.

A survey of the marketplace found 25 individual manufacturers of leak survey equipment and CGIs available in the U.S. (This survey is not intended to be a complete list of equipment). A total of 69 devices were available for purchase. Twelve devices did not state their detection technology.

Table 1 lists the five sensor technologies found in the market search and their percentage of the 58 total with known detection technology. Two of the technologies (catalytic bead and flame ionization) require the presence of oxygen to properly operate and must not be used in areas with depleted oxygen levels. Some devices utilize two sensor technologies and therefore have multiple ranges; for ease of comparison we have normalized the percentages by individual detector technology in the table to add up to 100%.

Table 1. Common Leak Detector Technologies

Technology	Advantages	Disadvantages	%
Semiconductor	Inexpensive, long life	Sensor contamination	39
Catalytic bead	Inexpensive	Finite lifetime, contamination	27
Infrared (IR)	Selective, wide range	Humidity, interferences	13
Thermal conductivity	Good for high conc.	Less sensitivity	14
Flame ionization (FID)	Responsive to combustibles	Requires hydrogen fuel	7

Table 2contrasts the various detection technologies inclusive of detection level and typical use. Readout units can be % LEL (Lower Explosive Limit) or parts per million(ppm). Some instruments allow the user to select the display units. Threshold detection limits vary with detector technology.

Table 2. Comparison of Leak Detector Technologies

Technology	Device Use/Purpose	Typical Range	Gas Detected
Semiconductor	CGI, leak survey	50-50,000 ppm	Flammable
Catalytic bead	CGI, leak survey	500-50,000 ppm	Flammable
Infrared (IR)	Leak survey	1-50,000 ppm	Methane
Thermal conductivity	CGI	1-100 % gas	Flammable
Flame ionization (FID)	Leak survey	0.1-50,000 ppm	Flammable

Infrared (IR) and Flame Ionization Detector (FID) sensors are the most sensitive, followed by semiconductor and catalytic bead. The sensitivity range of thermal conductivity detectors are appropriate for detecting concentrations of gas generally in the 1-100% gas in air range and are used in applications where oxygen is not required for use (purging operations etc.).

FID instruments have historically been used for outdoor buried pipe leak surveys and are more typical in applications where the survey environment is affected by variables such as wind, soil diffusion, and gas migration patterns thus requiring sensitivity thresholds to address these variables. IR detectors are used in mobile leak survey equipment like the Optical Methane Detector (OMD). IR spectroscopy is the underlying technology behind the Remote Methane Leak Detector (RMLD). A newer technology that uses Cavity Ring Down Spectroscopy (CRDS) is also based on IR spectroscopy.

Most devices have a hazard class rating of at least Class 1 Division 1, which enable their use in areas where explosive or combustible gases, vapors, or liquids are likely to be present, or present due to repair, maintenance, or equipment/process breakdown.

In addition to the information in the Table, other distinctions should be made between the types of detectors. Less expensive models generally do not have data logging capabilities or do not have a sampling pump. Sampling with a pump is more representative than a passive sampler that relies on the diffusion of test gas to the sensor. All of the leak survey equipment and most of the CGIs will alert the operator of the presence of combustible gas through both a visual alarm on the device along with an audible indication.

Periodic calibration is recommended by most manufacturers. The frequency of calibration varies by manufacturer, however not all of the lower cost devices have the ability to be calibrated. Common practice is to verify instrument performance before each day's use by a "bump" test exposing the sensor to a burst of methane gas to insure the sensor will respond to methane. It is recommended to periodically calibrate and bump test all equipment used for gas industry leak survey detection, whether the activity is for programmatic leak survey operations or for leak investigations. Each individual LDC must ascertain their own periodicity and calibration requirements based on manufacturer's recommendations. In NYS, all gas leak survey and leak detection equipment must be calibrated in accordance with the manufacturers recommendations *or* every 3 months.

Outdoor Leak Survey, Investigation, and Pinpointing Process

A pipeline leak *survey* is the act of systematically surveying the atmosphere in the vicinity of a pipe or a defined geographic area that bounds the area in which a subsurface pipe is known to be present for the presence of natural gas. The pipe being surveyed can be above ground or buried. Current NY State code requires the use of an approved instrument which continuously analyzes atmospheric samples and is capable of detecting the presence of gas in parts per million in air. The NY Department of Public Service has approved flame ionization and certain IR technology for code mandated leak surveys. Leak survey equipment can be hand held devices with an appropriate sampling probe, a flexible wand allowing the operator to locate a leaking area, or can be mounted on a vehicle for extended surveys.

Once a leak has been identified, either through a survey or a report from the general public (odor call), the process of leak *investigation and pinpointing* begins. The leak investigation process for suspected leaks on buried piping includes taking leak readings below ground from bar holes or sample access points using appropriate sample probes and filters for below ground samples. This process also includes sampling general contained atmospheres from buried structures (sewer, catch basin, manholes, etc.) and at locations outside a building wall such that the leak can be classified. A leak is then *pinpointed* before an excavation is made to repair the leak, pinpointing a leak source is typically accomplished through progressive leak readings from below grade bar-holes such that the probable leak location is sufficiently bounded and identified prior to suspected piping being exposed and repaired.

A survey of 15 LDCs in the northeast conducted for this report found that FID and IR-based devices were used by 72% of the respondents for leak surveys. When the process moved to leak investigations and pinpointing, CGIs dominated at 87%. Figure 1 graphs the responses.

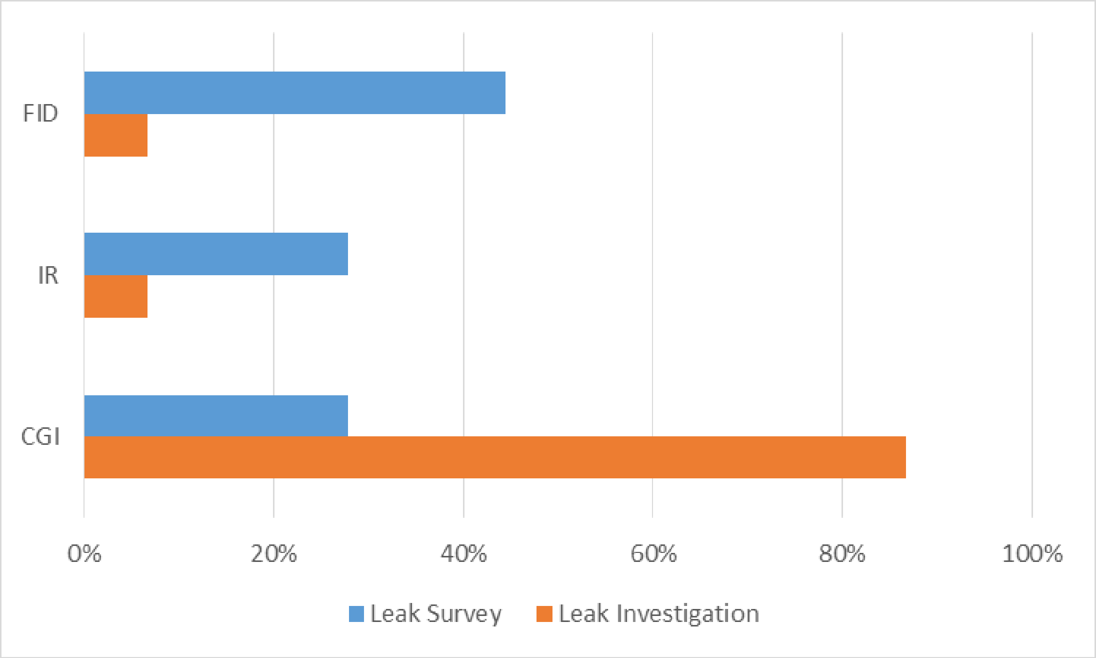

Figure 1. Equipment used for Leak Surveys vs. Leak Investigations

Indoor Leak Survey and Pinpointing/Investigation Process

On inside piping, fittings, or other equipment, a similar process is used as with outdoor leak surveys. The general area is first tested for the presence of combustible gas. The atmosphere in the area or along the path of the gas piping is then sampled for the presence of combustible gas. If combustible gas is found, the piping and appurtenances are further examined for a leak and the exact leak source is pinpointed. For inside piping, the same equipment (CGI) is often used for *both* the initial leak survey examination *and* the pinpointing investigation.

Air Quality and Personal Safety Monitors

Devices used for indoor leak survey and personal safety monitoring are usually smaller than the leak survey units, have similar detection thresholds and are intended to be clipped to a belt, hard hat, or other location on a person. Some have carrying straps and are worn over the shoulder. Many contain multiple sensors to check for oxygen, carbon monoxide (CO), and hydrogen sulfide in addition to combustible gas. Sensors for other gases are available from some manufacturers. Some companies use these devices as an initial survey tool followed by the same leak pinpointing process as described above.

A quick survey of the marketplace found 15 individual manufacturers available in the U.S. (as before, this survey is not intended to be a complete list of equipment.) A total of 43 devices were available for purchase.

Summary

Instruments for leak surveys and leak pinpointing/investigations are mature technology that have been on the market for many years. There are a variety of sensor technologies available depending on the practical application of the equipment and site specific conditions.

FIDs and IR-based technologies are used for leak surveys of buried piping because of the low threshold detection limit needed when the gas is diluted outdoors and/or reacts with the soil and buried environment.

CGIs are used for indoor leak surveys, outdoor and indoor leak investigations, and personal safety monitors. The majority of CGI detectors on the market rely on catalytic bead and/or metal oxide semiconductors. Each device type is used for a specific application and is considered fit-for-purpose for its intended use when coupled with an appropriate procedure.

(3) Leak Surveys - Outdoor Buried vs. Indoor Aboveground Situations

Outdoor aboveground surveys of buried piping systems are different from exposed indoor aboveground surveys. One obvious difference is the fact that the leaks from buried piping systems need to migrate from the leak site through soil or other dense material, to eventually diffuse into the atmosphere where they can be detected. The ability of natural gas to vent at the ground surface is critical for the success of an above ground survey of buried piping.

Outdoor Aboveground Leak Surveys of Buried Piping Systems

When measuring leaks outside, consideration must be made for gas migration, reaction mechanisms, and diffusion of gas into the atmosphere. Methane is lighter than air and will rise quicker than other gases, following the path of least resistance. Large leaks could generate a plume of methane that would rise with directional momentum. Smaller leaks will slowly diffuse through soil and gradually mix with air. In that instance, the density would be much closer to air and the methane concentration much lower due to dilution. Windy conditions will quickly dilute the gas further. Because of the inherent dilution potential due to atmospheric conditions and gas migration, it is critical to use equipment with an appropriate detection threshold and fit for purpose for the application. This threshold detection level is typically in the parts per million range.

Soil chemistry and makeup may also play a part. Volatile organics such as methane can be adsorbed by the clay matrix in soil, leading to false negative reports of small leaks. Methane may also be lost through oxidation by methanotrophic bacteria in the aerobic zones of soils. Methane loss appears to be positively correlated with temperature. Water content of the soil will collect in the voids between the soil particles and obstruct the rise of methane to the surface. In wet or frozen conditions, the gas may be restricted from venting. Other obstructions include ground surface treatments. If the leak is under concrete or asphalt it may travel a distance from the source, following the path of least resistance until it finds a point where it can vent to atmosphere.

Continuous sampling of the atmosphere within a defined geographic area that bounds the pipe of concern (pattern survey) or along the path of buried main and services should be made at close proximity to ground level, typically 2-6 inches above the ground surface. In areas where the gas piping is under pavement, samplings should also be at curb lines, available ground surface openings (such as manholes, catch basins, sewers, power, telephone duct openings, fire and traffic signal boxes, or cracks in the pavement or sidewalk), or other interfaces where the venting of gas is likely to occur. In the case of any exposed piping subject to similar environmental variables, sampling should be adjacent to the piping. The pace of the survey is dependent on the equipment used and is typically addressed in application procedures.

All these factors influence the selection of leak survey instruments with respect to the detection threshold. Again, and for the reasons note above, leak survey equipment used in outdoor *aboveground* surveys of *buried* piping systems must be capable of detecting gas in air at the parts per million level.

Indoor Leak Investigations

Leak investigations of exposed piping in aboveground, *indoor* environments are typically not significantly influenced by environmental variables similar to those for outdoor surveys of buried piping. However, indoor environments have their own specific considerations such as accessibility of the pipe, confined space, and leak diffusion. Some examples of above ground leaking components are worn/aged gaskets and seals such as leaks at pipe threads, valve packings, pressure regulator relief valves, atmospheric vents, etc. Inside a residential building, leaks may be from appliances, fittings, meters, regulators, and very importantly, migration of exterior buried piping leaks into a building structure.

Indoor environments have a distinct leak survey advantage over outdoor environments, in that the pipe is predominantly exposed within the building allowing the gas to be generally contained in the vicinity of the pipe. This enables direct gas sampling of the atmosphere in the vicinity of the pipe without influences from external variables affecting the presence and migration of gas relative to the pipe location. For pinpointing, this direct accessibility enables a continuous gas/air sample to be drawn in close proximity along the path of the pipe, typically 6” or less from the pipe itself. This means that the leaking gas does not have time and space to dilute in the surrounding air and provides a higher concentration vs. a similar size leak from a buried pipe outdoors that has to migrate to the surface and then is diluted with outdoor air. The lack of dilution enables the process of identification of hazardous leaks in indoor environments to be conducted at a different threshold of detection, typically parts per thousand, and enables the use of CGIs for this activity.

A significant difference between indoor vs. outdoor leak surveys is the limited ability of a gas leak to diffuse in an indoor environment. The physical constraints of the building confine the vast majority of the escaping gas to a limited area inside the building such as basements, attics and dead air spaces. Gas movement between rooms is obstructed by floors, walls, ceilings and closed doors.

The orientation of a gas source within a room will result in different gas-air distributions. Leaks at elevated pressure have a greater impact than leaks at residential/equipment utilization pressure because there is more driving force for the leak at higher pressure, and higher concentrations of gas in the surrounding environment. This limited ability of gas to diffuse and dilute within a building, by its very nature, creates an opportunity for a hazardous condition to develop because the gas can accumulate within the confines of the building or interior space.

The obvious limitation of indoor leak survey is the limited access to gas piping where it is concealed within building walls, ceilings and utility chases. In these cases, the survey operation extends along the gas pipe to the physical boundary imposed by the construction of the building. If access is available to the confined space where the gas pipe is present, then the survey probe is typically used to sample the air in those limited locations. Beyond this practice, the general public is warned of a potential gas leak through the use of odorant injected into the gas supply. Federal code stipulates that gas be readily detectable to the average person's olfactory sense at a concentration of 20% LEL. New York has a lower (more conservative) state code for odorant detection (10% LEL – parts per thousand) that supersedes the Federal code.

Summary

In general, outdoor environments require more sensitive instrumentation due to the dilution, migration, reaction, and diffusion of methane in that environment. Indoor gas leaks are in a controlled and contained space, where concentration can build easier over time, are less affected by external environmental variables, and result in a situation that does not require as sensitive an instrument and associated low detection threshold set point to achieve similar operational and public safety benefits. Instrumentation for both applications should be selected on a fit for purpose basis with an appropriate procedure for use.

(4) Sensitivity Considerations and False Positives and Negatives

While it may seem to be counter intuitive, if the set point or instrument threshold detection limit is too low (i.e., too sensitive), it may actually impede leak detection. Devices used for outdoor, aboveground leak surveys require much higher sensitivity and lower threshold detection limits to properly assess if a leak is present. This is fundamentally related to the potential for dilution and reaction as discussed earlier. These conditions are *not* present in indoor leak survey operations.

False Positives

The reason that leak detection instruments for indoor leak survey may be too sensitive is the concept of "false positives." A false positive is a situation in which a result improperly indicates the presence of a condition that is actually not present. In the presence of a background combustible gas concentration at the parts per million level, a leak investigation worker may not be able to accurately identify a leak using equipment that is too responsive to low levels of combustible gas that may result from background materials such as household chemicals. The device may trigger a false alarm when the conditions are only slightly above background for example when exposed to certain pipe joining compounds. As a result, the use of leak survey equipment for indoor piping at the parts per million detection threshold may hinder an effective and efficient leak survey process.

It should be noted that NY LDC leak investigation practices prescribe the use of CGIs at the parts per thousand detection threshold to investigate potential indoor leak claims. CGI use is a long accepted past practice that has a proven track record of safety. We specifically note here the difference between the leak survey process and the leak investigation process. This same approach is suggested within the GTI Atmospheric Corrosion Study and for broader use as a leak survey practice for NY LDCs. This does not prohibit the use of more sensitive leak detection equipment during the leak investigation process as warranted by the site-specific conditions.

False Negatives

The opposite of a false positive is a "false negative," which is a result that improperly indicates no presence of a condition (the result is negative), when in reality the condition is present. Catalytic bead and FID sensors require the presence of oxygen to work properly. If the oxygen level is low, they will not work and may give a false sense of security because the methane concentration display is low even when true methane levels are much higher.

There is potential for this situation to occur in an indoor leak survey. For example, if a leak was found in a utility chase, this smaller "confined" space could have a higher methane concentration with a resulting lower oxygen concentration. Using one of the detectors that require oxygen to operate, such as an FID, might give a falsely low reading for a combustible gas concentration. OSHA released a Hazard Information Bulletin discussing the use of combination oxygen and combustible gas detectors. Workers should understand the limitations of these detectors and correlate the oxygen content with less than LEL readings that may potentially be much higher.

(5) Margin of Safety to LEL and Threshold Detection Levels

The margin of safety is a measure of how well a design satisfies the design requirements for its intended application. For the application of monitoring combustible gas, the margin of safety is a measure of the difference between an instrument's detection threshold, and the intrinsic safety requirement of the measurement operation. Each individual LDC must determine their own margin of safety requirements.

Leak survey and investigation equipment commonly report data as % LEL, % gas in air, parts per million (ppm) by volume of gas, or parts per thousand. Table 3 shows how the different units compare for several concentration levels.

Table 3. Correlation of Different Units of Methane Concentration

% LEL	% Gas in Air	Methane, parts per million	Methane, parts per thousand
100%	5%	50,000 ppm	50 parts per thousand
10%	0.5%	5,000 ppm	5 parts per thousand
1%	0.05%	500 ppm	0.5 parts per thousand
0.1%	0.005%	50 ppm	0.05 parts per thousand
0.01%	0.0005%	5 ppm	0.005 parts per thousand

The following are example calculations for common threshold detection limits found with typical leak investigation (CGI) and leak survey (FID) equipment.

If the CGI set point (threshold detection value) is 0.1% gas in air (2% LEL) this equates to one part per thousand, or 1000 parts per million. Most CGIs are capable of reaching this threshold detection limit. Using the LEL value of methane (5% gas in air), the relative difference between the threshold detection limit and the LEL value is 50 times. This means that there would be a margin of safety of 50 times with the CGI use. The 0.1% gas in air is the level of detection for CGIs currently being used by some NY LDCs for inside leak investigation. This is also the level of detection proposed within the GTI Study for inside leak survey and the level of detection associated with "belt-clip" CGIs proposed for broader use in New York State within the Staff Straw Proposal as part of Case 15-G-0244.

The same calculation can be made for an FID instrument. An FID threshold detection value of 1 part per million is 0.0001% gas in air, or 0.002% LEL, or 0.001 parts per thousand. Comparing again to the LEL value for methane, the relative difference between the threshold detection limit and the LEL value is 50,000 times. The margin of safety for FID instruments used for inside leak survey is therefore 50,000.

Material margins of safety are often published in technical standards but there is no dedicated standard to this subject. One source (www.engineeringtoolbox.com) lists margins of safety for engineering design ranging from 1.5 to 20 times, depending on the application. The 50 times margin of safety of most commonly available CGIs is greater (more than two times) than this highest estimated margin of safety for engineering design.

Residential Methane Detectors (RMDs)

Residential methane detectors are small AC powered plug-in devices intended to detect natural gas (methane) which may be present in a residential building. These devices are intended to sound an alarm at or above 25% LEL of natural gas or LP-Gas. Japan is currently the only area that mandates the presence of an RMD in homes.

The 25% of LEL set point of RMDs translates to 1.25% gas in air, 12.5 parts per thousand, or 12,500 parts per million. Using the same LEL of methane logic as above (5% gas in air), the difference between the set point of RMDs and the LEL value is 4, giving a margin of safety of 4 times. Legislation is being considered in New York to require RMDs in residential areas. Recommendations are underway to reduce the RMD set point to 10% LEL (0.5% gas in air, 5,000 parts per million, or 5 parts per thousand), with a difference between the set point and the LEL of methane of 10, increasing the margin of safety to 10 times.

Table 4 summarizes the margin of safety information for typical leak investigation (CGI) and leak survey (FID) equipment, plus the existing and proposed RMD standards. The CGI devices have a greater margin of safety than RMDs and many common engineering designs. Their margin of safety is not so large to induce false positives from background methane levels.

Table 4. Margin of Safety for Various Devices

Common Device	Lower Threshold Detection Limit or Set Point	Margin of Safety, Compared to Methane LEL
CGI	0.1 % gas in air	50
FID	1 ppm	50,000
RMD	25% LEL	4
RMD proposed	10% LEL	10
Odorant Detection (NYS)	10% LEL	10

(6) Natural Gas Odorant Considerations

Because methane by itself is odorless, odorants have been added to natural gas streams in the United States ever since the 1937 Texas school explosion. The requirement that gas in certain classes of natural gas transmission and distribution pipelines be odorized (or contain a natural odorant) is prescribed in the Code of Federal Regulations (CFR) Title 49 Part 192.625. The purpose of the odorant is for people to quickly detect if a natural gas leak is present. Odorant serves as the primary means of leak detection for the general public. Odorant is considered by some as the, “last line of defense” for leak detection.

The text in 49 CFR 192.625 specifies an odorant concentration to be detected by a normal sense of smell at 20% LEL, while some states such as New York and Maryland are lower at 10% LEL, and Massachusetts is even lower. As these current codes and regulations stand today, a leak survey worker in New York would be more likely to smell gas in an indoor space prior to any residential methane detector activating an alarm. Using a CGI device with a threshold detection value of 0.1% gas in air (2% LEL) would enable the detection of gas even earlier as the CGI would detect gas at a detection threshold 5 times lower than the odorant detection threshold in New York.

Following the margin of safety reasoning in the previous section, the 10% LEL level of odorant detection in New York equates to a margin of safety of 10 compared to the LEL of methane.

(7) Having Greater Numbers of Leak Survey Instruments in the Field

The majority of NY LDC field technicians are already equipped with CGIs, all of which have the ability to be used for inside leak surveys. At least one NY LDC is already using belt clip leak detectors that are equivalent to traditional CGIs but in a more compact form.

The advantage of having many more CGIs (including belt clip detectors) in the field is clear. The public safety benefit of enabling these devices to be used for leak survey of indoor piping will enable significantly more surveys to be performed on an ongoing basis versus limiting leak surveys to more expensive and overly sensitive, specialized equipment (as it relates to indoor leak surveys). There are significant public safety benefits in enabling more surveys to be performed and this could be achieved by expanding the type of fit-for-purpose equipment approved within New York for indoor leak surveys.

In the situation where an abnormal combustible gas concentration is detected, a more sensitive instrument could be made available by the LDC to confirm the reading or assist in the leak investigation process.

Conclusions

The survey protocol proposed within the GTI Atmospheric Corrosion Study and attached here as Appendix A recommends the use of CGIs with a level of detection at the parts per thousand level for leakage survey of indoor piping systems. This approach, inclusive of both the type of equipment and threshold level of detection, is consistent with existing LDC practices for leak investigation inside buildings. The level of detection at the parts per thousand level is appropriate for this leak survey application since:

- Most of the inside gas piping is directly accessible for survey inside the building as opposed to buried piping systems where soil characteristics impede the leak migration to the ground level for detection.
- Leakage is contained and concentrations will build within the confines of the structure and does not quickly dissipate, as is the case in an outdoor environment.
- Detection thresholds at a parts per thousand level have historically enabled the identification of potentially hazardous leaks on inside piping systems.
- Use of leak survey equipment on indoor piping at the parts per million detection threshold frequently hinders the leak survey process as the background methane level may exceed this threshold when a leak is present.
- Once a leak is detected at the parts per thousand level during a leak survey, the LDC begins its leak investigation process. An instrument at the parts per million detection threshold can be utilized, if necessary, during this follow on process to accurately pinpoint the leak.
- The parts per thousand detection level is within the same order of magnitude (while being five times lower) for the level of detection of natural gas odorant in NY, which is the primary means for the general public to identify a natural gas leak.
- A CGI with a threshold detection value of 0.1% gas in air (one part per thousand) has a 50 times margin of safety as compared to the LEL value of methane.
- LDC leak survey technicians and emergency response personnel are already equipped and trained in the use of a CGI for leak investigation of inside piping systems. The use of this equipment at these levels will be more efficient and cost effective if the CGI is approved for use in this application.

CGIs should be considered fit-for-purpose for indoor leak surveys.

Appendix A – Leak Survey Protocol for the GTI Atmospheric Corrosion Study

The listed items below cover leak survey inspection of visibly accessible indoor natural gas piping, regulators, fittings, and meters; including the wall penetrations or point of entry (POE) to the interior of the building through the outlet of the meter.

1. The operator is responsible for satisfying all internal safety procedure requirements, training and operator qualification requirements. This procedure does not address such requirements.
2. All reasonable efforts shall be made to survey and inspect visibly accessible service piping.
3. Document any piping that was obstructed and any incomplete portions of the inspection.
4. Leak surveys will be conducted using a conventional portable combustible gas indicator[a] (CGI) with a 0.1% gas reporting threshold.
5. The leak survey is to be conducted by assessing the general atmosphere approximately 6” from the pipe/fitting/meter using an appropriate sample probe[a].
6. If multiple leaks are found during the leak inspection, record only the highest reading[b].
7. In an instance when an abnormal combustible gas concentration is detected, a more sensitive instrument can always be requested to confirm the reading.

Notes:

a. A component of the GTI Study will compare the results of the above indoor leak survey protocol with leak surveys performed with belt clip CGI leak detectors.

b. Item 6 applies only to data collection for the GTI Study and is not broadly applicable to LDC leak survey protocols.

Appendix B –Brief Discussion of Conventional Combustible Gas Sensor Technologies

Catalytic bead detectors (Figure 2) were the first combustible gas detectors in the market. They function by oxidizing (burning) the combustible gas at the hot surface of the bead and measuring the resultant change in resistance of the bead, which is directly proportional to concentration. They are relatively low-cost and well established. They have an approximate life span of five years because the oxidation process consumes the sensor material, and it eventually depletes and becomes unresponsive. Catalytic bead sensors respond to all combustible gases but they respond at different rates to each and so can be calibrated for particular gases in specific applications. The bead surface can be contaminated by certain gases and reduce sensitivity and lifetime.

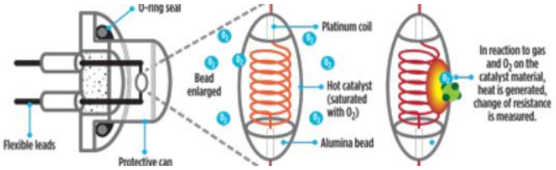

Figure 2. Catalytic Bead Sensor

Image from Reference 4

Semiconductor based combustible gas detectors (Figure 3) were introduced in the late sixties as an alternative to the catalytic bead. They are usually constructed from transition metal oxides. With these sensors, gas is adsorbed onto the sensor surface, changing the resistance of the metal oxide. Concentration of the combustible gas is proportional to the resistance. When the gas disappears, the sensor returns to its original condition. No sensor material is consumed in the process, and as a result, they can have a longer life expectancy. Like the catalytic bead sensor, they are susceptible to contamination. Sometimes the interferences from other gases are minimized by using appropriate filtering materials that absorb all other gases except the gas to be detected. This is a common application in semiconductor sensors used for the residential methane detector market.

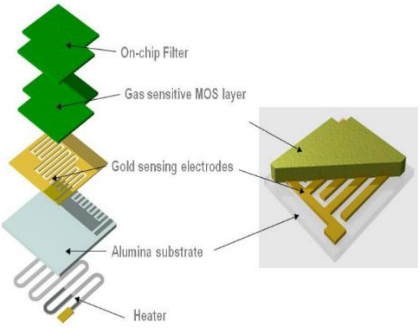

Figure 3. Semiconductor Sensor

Image from Reference 5

Infrared sensors (Figure 4) work on the principle that gases containing two or more dissimilar atoms absorb infrared radiation in a unique manner that can be easily detected. Each gas has a unique fingerprint spectrum and specific bands of the spectrum are targeted for analysis. As the gas concentration increases, the absorption band increases. Infrared sensors are highly selective and offer a wide range of sensitivities, from parts per million levels to 100 percent concentrations. The selection of the band for monitoring is important to eliminate interferences from other gases that might be present such as ambient humidity.

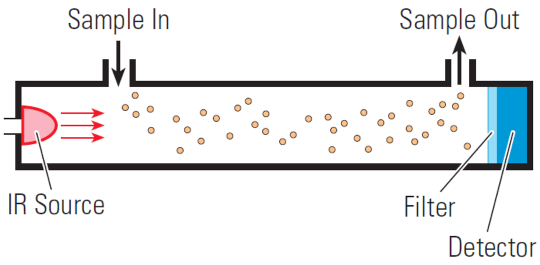

Figure 4. IR Sensor

Image from Reference 1

A **flame ionization** detector (FID, Figure 5) is a general-purpose detector used to determine the presence of volatile carbon-based compounds that are burned in a hydrogen-air flame. When the organic compounds burn, ions are generated that cause an increase in the flame's baseline ion current at a collection electrode in proximity to the flame. The more carbon atoms a molecule contains the greater the response. They are commonly used as detectors for gas chromatography but can also be used as standalone monitors for leak detection. Despite the hydrogen/oxygen flame, these devices are usually rated as intrinsically safe and can be used in Class 1 Division 1 locations.

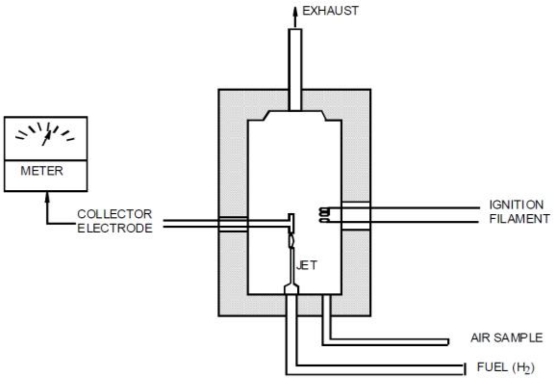

Figure 5. FID Sensor

Image from Reference 6

Thermal conductivity detectors (TCD, Figure 6) work on the principle that gaseous compounds possess different heat conduction characteristics (thermal conductivity). By comparison to a sealed reference gas cell containing one thermistor in air, a second thermistor will change temperature as gas composition changes. When tuned to respond to combustible gases, it can be used as a wide range detector for high concentration levels.

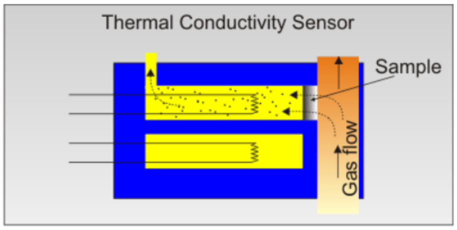

Figure 6. TCD Sensor

Image from Versaperm Ltd.

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END OF WHITE PAPER

GTI PROJECT (21858)

Indoor Atmospheric Corrosion and Leak Survey Risk-Based Intervals

Opportunitic Sample Analysis Addendum Report

August 25, 2017

Submitted To

Northeast Gas Association (NGA)

GTI Technical Contact
Mr. Daniel Ersoy
R&D Executive Director
Gas Technology Institute
847.343.9755
daniel.ersoy@gastechnology.org

Authors
Daniel Ersoy, M.Sc., CIP, APMP
Khalid Farrag, PhD, P.E., PMP

Gas Technology Institute
1700 S. Mount Prospect Rd
Des Plaines, Illinois60018
www.gastechnology.org

Signature Page

		Date
AUTHOR Daniel A. Ersoy	Daniel Ersoy//S//	August 25, 2017
	Title: R&D Executive Director, GTI	
CO-AUTHOR Khalid Farrag	Khalid Farrag//S//	August 25, 2017
	Title: Sr. Institute Engineer, GTI	
REVIEWED BY Daniel Dessanti	Daniel Dessanti//S//	August 25, 2017
	Title: Project Manager, NGA	

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The results within this report relate only to the items analyzed.

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Executive Summary

This report is an addendum to the final report, GTI Report 21858, *Indoor Atmospheric Corrosion and Leak Survey Risk - Final Report - August 25, 2017* which summarized the development and execution of a random sampling plan and methodology used by New York (and one New Jersey) state operators to gather field data to evaluate the appropriate frequency for mandated inspections of indoor jurisdictional piping and appurtenances.

This addendum report describes the data analysis from an opportunistic sampling plan and methodology used by four New York state operators to gather field data in 2016 to evaluate the appropriate frequency for mandated inspections of indoor jurisdictional piping and appurtenances.

Opportunistic inspections might include situations like odor investigations, poor pressure complaints or other situations where properly qualified technicians respond to a location and gain access. The data from the site surveys were combined and a trend analysis was performed. In some cases, it was hard to differentiate if the corrosion and leaks were upstream or downstream of the meter in numerous cases. When there was no explicit note that the leaks and corrosion were downstream of the meter they were included.

Whereas the random sampling program was designed in a deliberate manner to have random inspections with proportions reflective of the size of the operator systems, the opportunistic sample set is biased by definition. As noted above, these corrosion and leak inspections were added to an already scheduled customer visit for an odor investigation (i.e., site predisposed for a leak) or other maintenance or operational activity.

Four New York operators submitted data under the opportunistic sampling in 2016. The four data sets received for this sampling had very useful data, but were of somewhat different formats. Because of the variability in the data set and the inherent bias of the sample, a sensitivity and probabilistic analysis were not conducted.

However, the statistical analysis of the variable distribution and the corrosion severities and leak occurrences were completed and compared to the random sample done 2016.

The distribution of the sample set as measured by the system variables and the outcome of the corrosion severity and leak inspections were consistent with the random sample program completed earlier in 2017.

A total of 84,460 opportunistic inspections were submitted by the four NY operators. The results of the opportunistic surveys were analyzed by the variables recorded for each inspection, and showed there were approximately (number rounded to nearest %): 74% of the sites had the regulator outside the building and 26% inside the building; 49% were multi-unit, 39% single-unit, and 9% commercial/industrial; 61% had the meter near the POE, 29% indoor or remote, 10% in a meter room, and less than 1% were room sets.

The corrosion severity and number of leak indications vs non-leak indications were determined for the opportunistic sample set. For corrosion severity there were 96% with none/minimal corrosion, 3% low corrosion, 1% medium corrosion, and less than 1% with high corrosion levels. The proportion of the samples related to leak indications showed that 99% of the sites exhibited no leak indications while about 1% had an indication of a leak.

The findings of the opportunistic sample set were compared to the rolled-up findings of the random sample set and were found to be very similar at this high level.

One should still rely on the random sample study to determine what variables could lead to higher corrosion severity and/or leak percentages. The opportunistic study showed that at a high level, the opportunistic inspections provided a similar understanding of the overall corrosion levels as a proportion of the population, as wells as the overall leak indication rates and can provide a useful tool for trend analysis of an operators system for these attributes.

1 Background

As part of the NGA sponsored project, *Indoor Atmospheric Corrosion and Leak Survey Risk-Based Intervals*, an opportunistic sampling methodology was developed for use by New York operators to conduct corrosion and leak surveys during situations like odor investigations, poor pressure complaints or other situations where properly qualified technicians respond to a location and gain access.

The opportunistic corrosion and leak survey procedure developed for the data collection is provided in Appendix A.

This report provides a data analysis of the opportunistic surveys submitted to GTI and is an addendum to the final report GTI 21858, Indoor Atmospheric Corrosion and Leak Survey Risk - Final Report - August 25, 2017 which summarizes the development and execution of a random sampling plan and methodology used by New York (and one New Jersey) state operators to gather field data to evaluate the appropriate frequency for mandated inspections of indoor jurisdictional piping and appurtenances..

Whereas the random sampling program was designed in a deliberate manner to have random inspections with proportions reflective of the size of the operator systems, the opportunistic sample set is biased by definition. As noted above, these corrosion and leak inspections were added to an already scheduled customer visit for an odor investigation (i.e., site predisposed for a leak) or other maintenance or operational activity.

Four New York operators submitted data under the opportunistic sampling in 2016. Although a standard protocol was developed, the four data sets had different variables collected and did not report these variables or the responses for corrosion and leaks in the same way. Because of the variability in the data set and the bias of the sample, a sensitivity and probabilistic analysis were not be conducted.

However, the statistical analysis of the variable distribution and the corrosion severities and leak occurrences were completed and compared to the random sample done 2016 and are presented in this report.

2 New York State-Wide, Opportunistic Sample Size and Variables

This section provides a summary of the number of atmospheric corrosion and leak surveys in 2016 under this project. The field inspections in Table 1 below is through December 31, 2016.

This addendum report summarizes the findings from the 84,460 opportunistic inspections submitted by four NY operators. A proportion of the opportunistic inspections are missing different system variables or characteristics or even the indication of response (leak) data. For this reason, some of the tallies in the data and analysis tables will not add up to 84,460 later in this report.

Table 1. Program Inspection Sampling Summary

Operator	Random Submitted	Opportunistic Submitted
NGrid	8,387	**74,601**
PSEG (NJ)	2,641	**-**
ConEd	2,996	**9,334**
RGE	584	**1**
NFuel	177	**123**
NYSEG	511	**-**
Cent Hud	64	**401**
ORU	121	**-**
St. Lawrence	24	**-**
Totals	***15,505***	***84,460***

For an explanation of the system and environmental variables and the corrosion and leak responses, the reader is directed to the final report, *GTI 21858 Indoor Atmospheric Corrosion and Leak Survey Risk - Final Report - August 25, 2017.*

3 Opportunistic Sampling Program Corrosion and Leak Survey Results

The variables for Dwelling Type, Regulator Location, Meter Location are broken down into their respective categories and plotted in Figure 1 to Figure 3. Three of the four operators provided data for these variables, so the data set is incomplete, but still shows a good distribution of samples between the various categories for each variable.

The opportunistic inspections were on indoor piping vs. the short Point of Entry (POE) section of pipe specific to the location of building penetration.

The data from the Opportunistic Sample and Analysis is shown in Table 2. and the breakdown of corrosion severity levels and leaks vs. non-leaks are shown in Figure 4 and Figure 5.

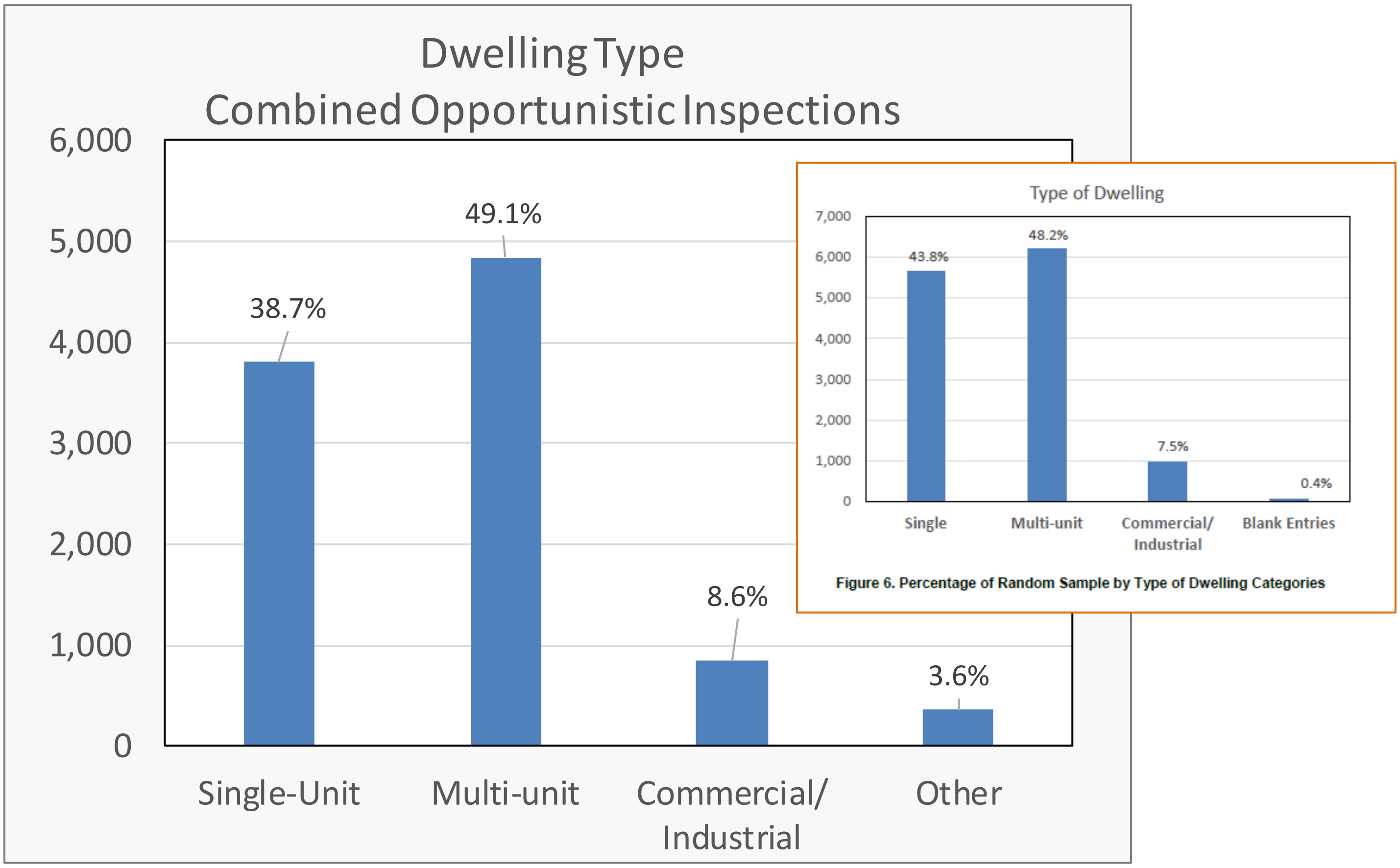


Figure 1. Percentage of Opportunistic Sample by Type of Dwelling Categories (Random Data Shown as Inset Plot)

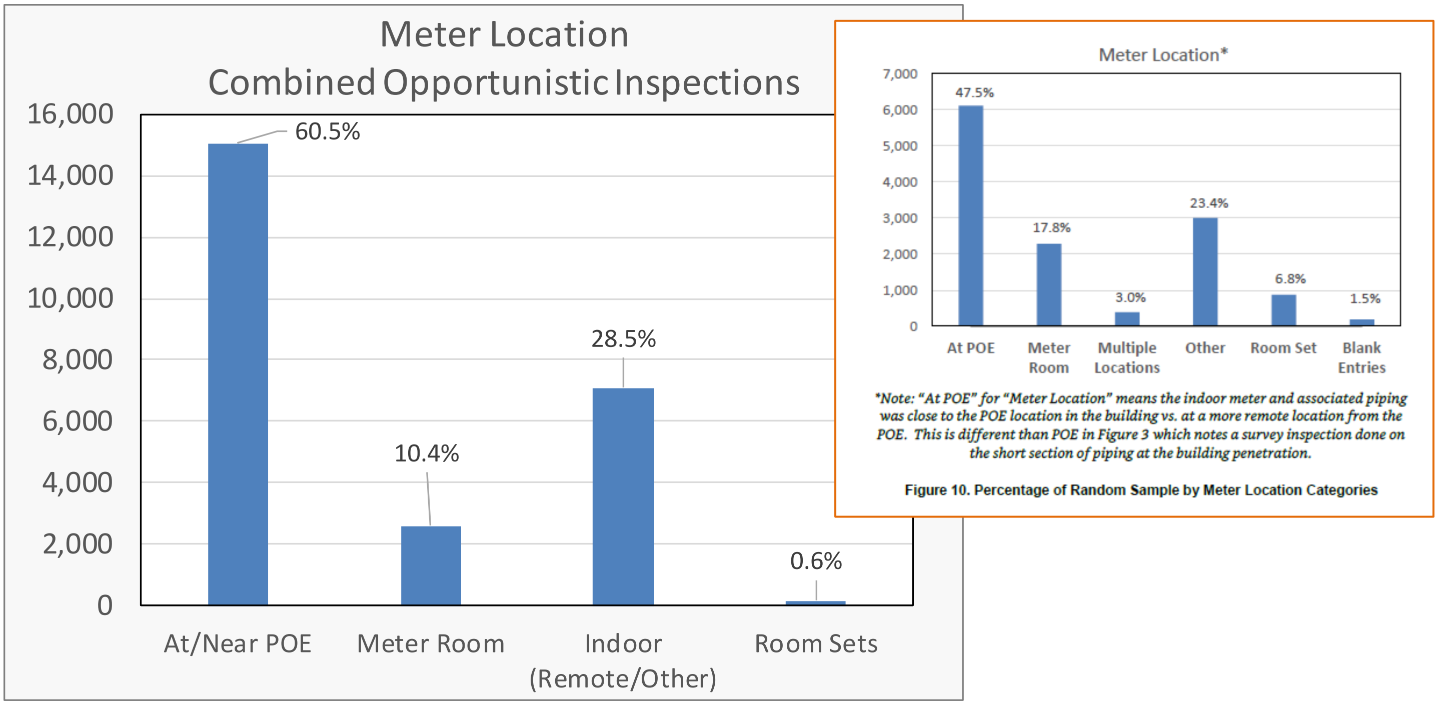


Figure 2. Percentage of Opportunistic Sample by Meter Location (Random Data Shown as Inset Plot)

**Note: "At POE" for "Meter Location" means the indoor meter and associated piping was close to the POE location in the building vs. at a more remote location from the POE.*

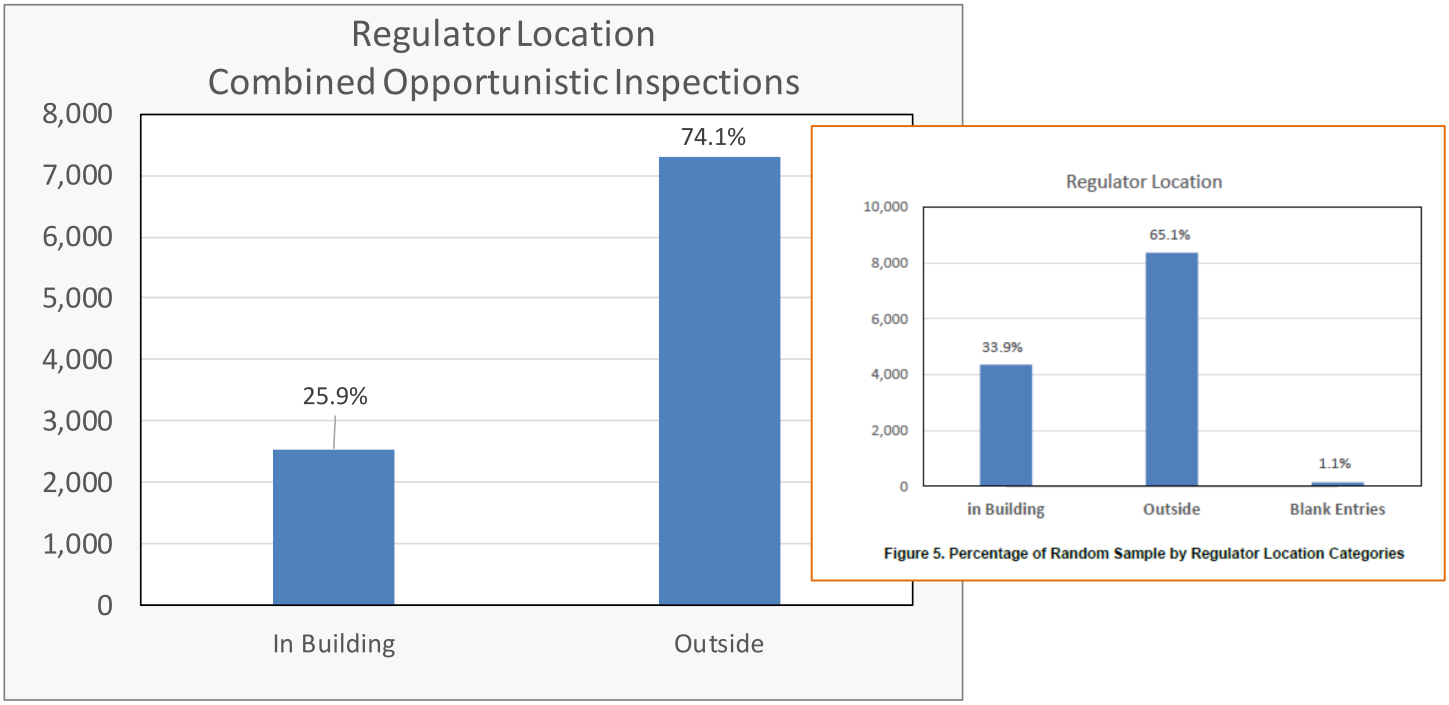


Figure 3. Percentage of Opportunistic Sample by Regulator Location (Random Data Shown as Inset Plot)

Table 2. Opportunistic Inspection Summary of Data and Analysis

Opportunistic Inspection Summmary		Ngrid				ConEd					CentHud + Nfuel	Combined
Variable	**Category**	**LI**	**NYC**	**UNY**	**Subtotals**	**Bronx**	**Manhattan**	**Queens**	**Westchester**	**Subtotal**	**Subtotal**	**Grand Totals**
Records	NA	13,715	44,026	16,860	74,601	3126	1353	1761	3092	9,332	524	84,457
Primary Location	Indoor Piping										520	520
	POE Section										2	2
Geographical	Rural/Urban	11,947			11,947							11,947
	Coastal/Industrial	1,768			1,768							1,768
Regulator Location	In Building					177	72	749	1,527	2,525	26	2,551
	Outside					2,949	1,281	1,012	1,565	6,807	491	7,298
Dwelling Type	Single-Unit					579	85	838	2,157	3,659	151	3,810
	Multi-unit					2,157	930	716	707	4,510	331	4,841
	Commercial/ Industrial					274	200	166	173	813	32	845
	Other					116	138	41	55	350	8	358
Meter Location	At/Near POE	8,777			8,777	1,391	715	1,394	2,342	5,842	436	15,055
	Meter Room	1,310			1,310	478	416	159	203	1,256	22	2,588
	Indoor (Remote/Other)	4,938			4,938	1,145	204	203	535	2,087	63	7,088
	Room Sets					112	18	5	12	147		147
Response	**Category**	**LI**	**NYC**	**UNY**	**Totals**	**Bronx**	**Manhattan**	**Queens**	**Westchester**	**Totals**	**Totals**	**Grand Totals**
Corrosion Severity	Non/Very Minimal	13,689	44,016	16,408	74,113	2,182	1,091	1,288	2,325	6,886	313	81,312
	Low	0	0	0	0	895	234	453	748	2,330	159	2,489
	Medium	0	0	452	452	25	12	15	11	63	41	556
	High	26	10	0	36	24	16	5	8	53	11	100
	% High	**0.19%**	**0.02%**	**0.00%**	**0.05%**	**1.57%**	**2.07%**	**1.14%**	**0.61%**	**0.57%**	**2.10%**	**0.12%**
Leak Reading	None/Other Locations	13,631	43,426		57,057	3,091	1,340	1,711	3,046	9,188	513	66,758
	Leak	84	600		684	35	13	50	46	144	11	839
	% Leak	**0.61%**	**1.36%**		**1.18%**	**1.12%**	**0.96%**	**2.84%**	**1.49%**	**1.54%**	**2.10%**	**1.24%**
			Note 1	*Note 2*		*Note 3*		*Note 4*	*Note 5*			

Notes

1. The 600 leaks in NYC are at meters, meter connections, and regulators. Assumption was that all the meters and regulators are indoor (based on NG correspondence that all this data is indoor).
2. There was no leak data provided for NYC and for this reason the leak area is highlighted as grey similar to other areas in the table where data was not provided.
3. Total Leaks in Bronx of 57 includes 22 leaks reported as in appliances. Thus the indoor number of leaks are only 35, resulting in a %leak of 1.1%.
4. Similarly, total leak in Queens (58) includes 8 leaks in appliances. This results in 50 leaks and %leak of 2.8%.
5. Similarly, total leak in Westchester of 54 includes 8 leak in appliances, results in in a %Leak of 1.5%.

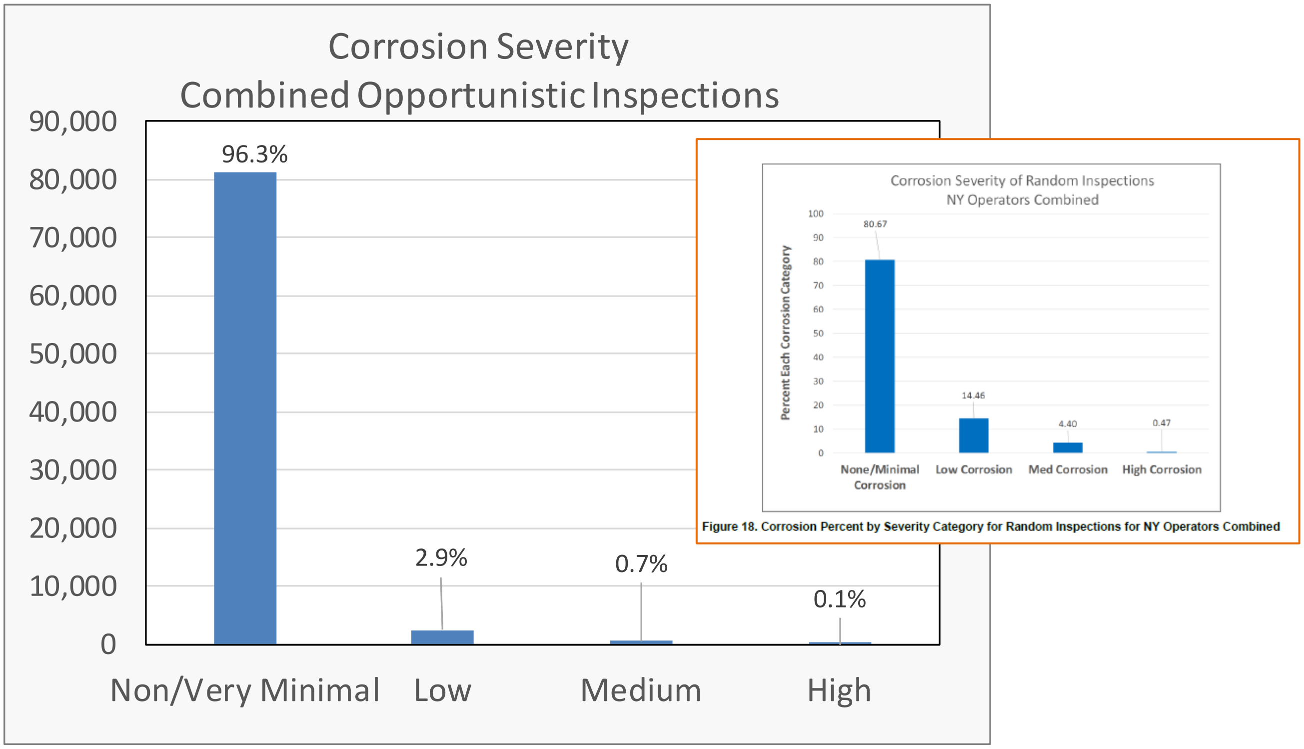


Figure 18. Corrosion Percent by Severity Category for Random Inspections for NY Operators Combined

Figure 4. Corrosion Percent by Severity Category for Opportunistic Inspections (Random Data Shown as Inset Plot)

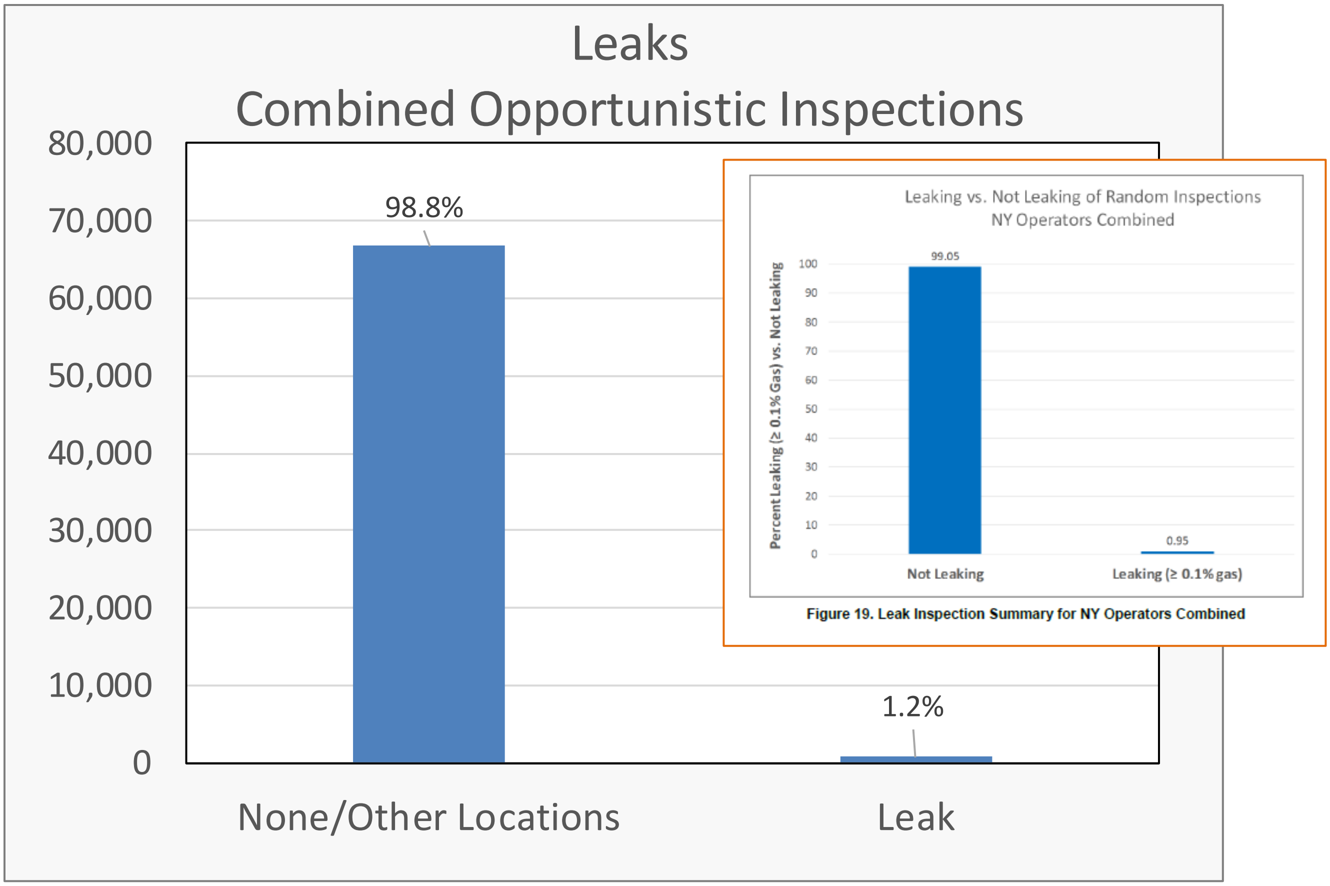


Figure 5. Leak Inspection Summary for Opportunistic Inspections (Random Data Shown as Inset Plot)

4 Conclusions

The opportunistic sampling program was conducted over approximately one year in 2016, the same as the random sampling program. This period allowed the study to address typical indoor environmental operating variables an operator may experience in day-to-day operations throughout one complete cycle of seasons. A total of four New York operators participated in the opportunistic corrosion and leak surveys.

A standardized protocol (Appendix A) for conducting both atmospheric corrosion inspections and indoor piping leak surveys was developed for the opportunistic program. The four data sets received for this sampling had very useful data, but were of somewhat different formats, potentially due to the collection of data being undertaken prior to implementation of the protocol. Because of this we could not do a sensitivity or probability analysis of the sampling data.

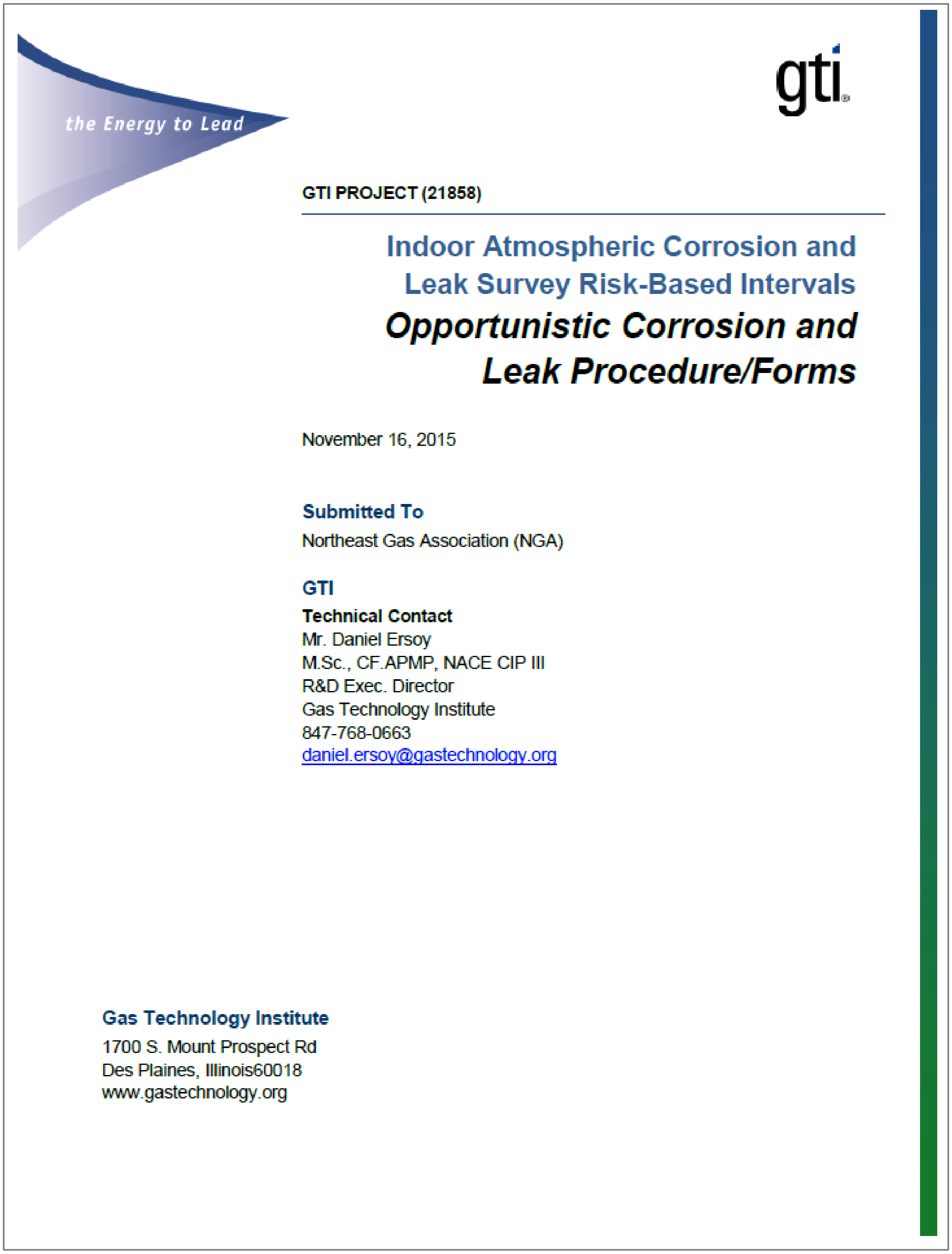
A total of 84,460 opportunistic inspections were submitted by the four NY operators. The results of the opportunistic surveys were analyzed by the variables recorded for each inspection, and showed there were approximately (number rounded to nearest %): 74% of the sites had the regulator outside the building and 26% inside the building; 49% were multi-unit, 39% single-unit, and 9% commercial/industrial; 61% had the meter near the POE, 29% indoor or remote, 10% in a meter room, and less than 1% were room sets.

The corrosion severity and number of leak indications vs non-leak indications were determined for the opportunistic sample set. For corrosion severity there were 96% with none/minimal corrosion, 3% low corrosion, 1% medium corrosion, and less than 1% with high corrosion levels. The proportion of the samples related to leak indications showed that 99% of the sites exhibited no leak indications while about 1% had an indication of a leak.

The findings of the opportunistic sample set were compared to the rolled-up findings of the random sample set and were found to be very similar at this high level.

One should still rely on the random sample study to determine what variables could lead to higher corrosion severity and/or leak percentages. The opportunistic study showed that at a high level, the opportunistic inspections provided a similar understanding of the overall corrosion levels as a proportion of the population, as wells as the overall leak indication rates and can provide a useful tool for trend analysis of an operators system for these attributes.

5 Appendix A - Opportunistic Inspection Protocol



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GTI PROJECT (21858)

Indoor Atmospheric Corrosion and Leak Survey Risk-Based Intervals

Opportunistic Corrosion and Leak Procedure/Forms

November 16, 2015

Submitted To
Northeast Gas Association (NGA)

GTI
Technical Contact
Mr. Daniel Ersoy
M.Sc., CF.APMP, NACE CIP III
R&D Exec. Director
Gas Technology Institute
847-768-0663
daniel.ersoy@gastechnology.org

Gas Technology Institute
1700 S. Mount Prospect Rd
Des Plaines, Illinois60018
www.gastechnology.org

Opportunistic Indoor Atmospheric Corrosion and Leak Survey Inspections

This document provides guidance for the *opportunistic* inspections. These might include situations like odor investigations, poor pressure complaints or other situations where properly qualified technicians respond to a location and gain access. A separate, slightly more detailed, procedure and set of forms will be developed for a *random* sampling program that will be executed in 2016.

The listed items below cover the general and common information for the opportunistic visual corrosion and leak survey inspection of visibly accessible indoor natural gas piping, regulators, fittings, and meters; including the wall penetrations or point of entry (POE) to the interior of the building through the outlet of the meter.

1. The operator is responsible for satisfying all internal safety procedure requirements, training and operator qualification requirements. This procedure and the associated forms do not address such requirements.
2. Use the included *Indoor Atmospheric Corrosion and Leak Assessment Form* (and companion visual comparator) to help guide and record all findings.
3. All reasonable efforts shall be made to survey and inspect visibly accessible service piping.
4. Document any piping that was obstructed and any incomplete portions of the inspection.
5. Leak surveys will be conducted using a conventional portable combustible gas indicator (CGI) with a 0.1% gas reporting threshold. The leak survey is to be conducted by assessing the general atmosphere approximately 6" from the pipe /fitting/meter using an appropriate sample probe.

(Optional) Several participants will be evaluating a belt clip type combustible gas monitor to assess comparative results from the pipe survey in #5 above vs the general atmosphere while walking and visually assessing the piping /piping components for atmospheric corrosion. If a leak indication is identified with the CGI assessment in #5 and is not detected on the belt clip device or visa-versa, the readings shall be documented on the form. The belt clip general atmosphere devices will have the same detection threshold as the conventional CGI in #5 (0.1% gas detection threshold).

Required Inspection Field Form and Visual Comparator (on next 6 pages)

Section

A. General Information for the Survey
B. Indoor Atmospheric Corrosion Inspection
C. Indoor Leak Measurement Inspection
D. Visual Comparator for use with Indoor Corrosion Inspection[1]

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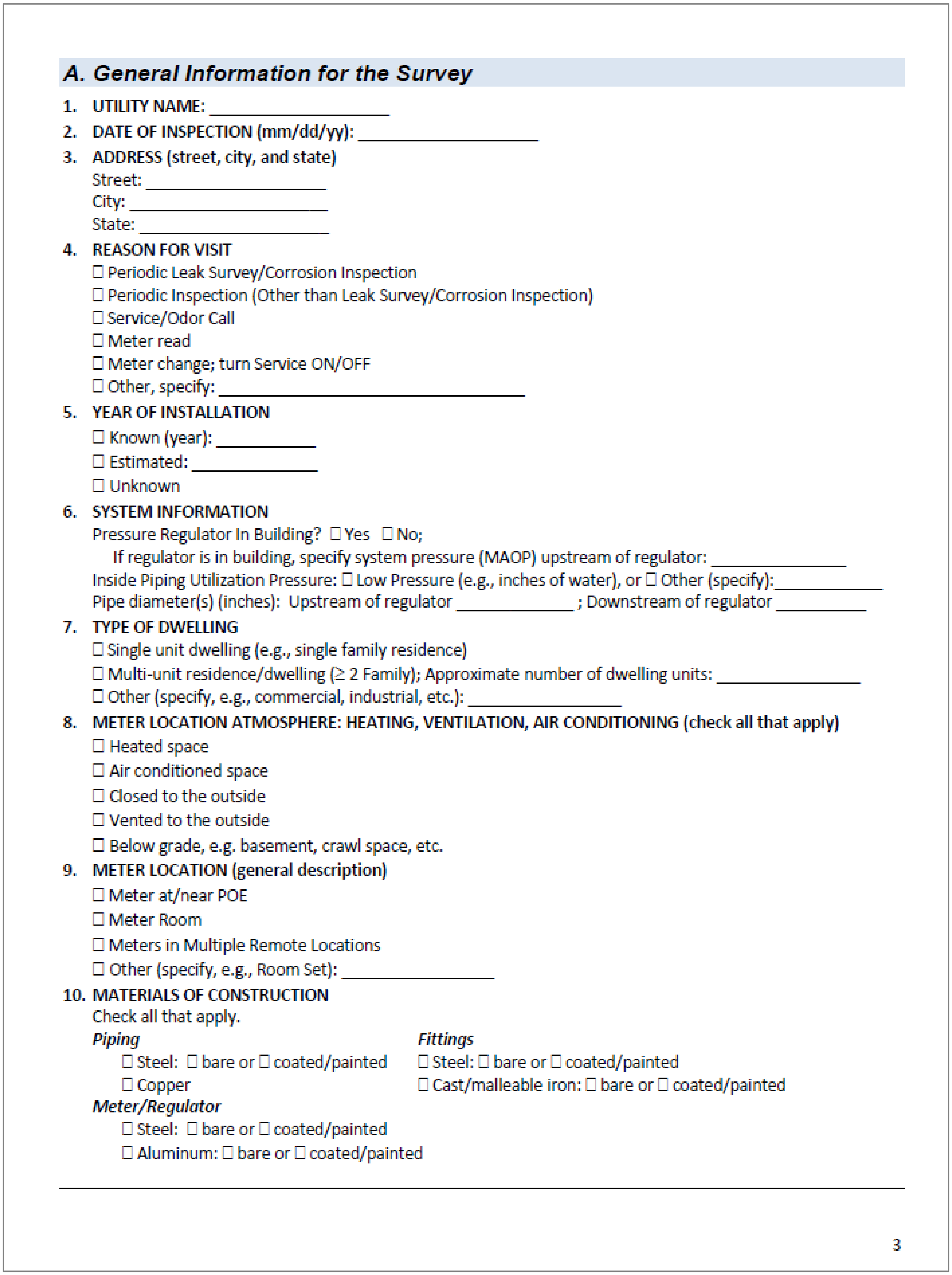
[1] The visual comparator is based on SSPC Vis-1 and Vis-3 standards, and discussions between NGA and SSPC may be needed to acquire them for their planned use.



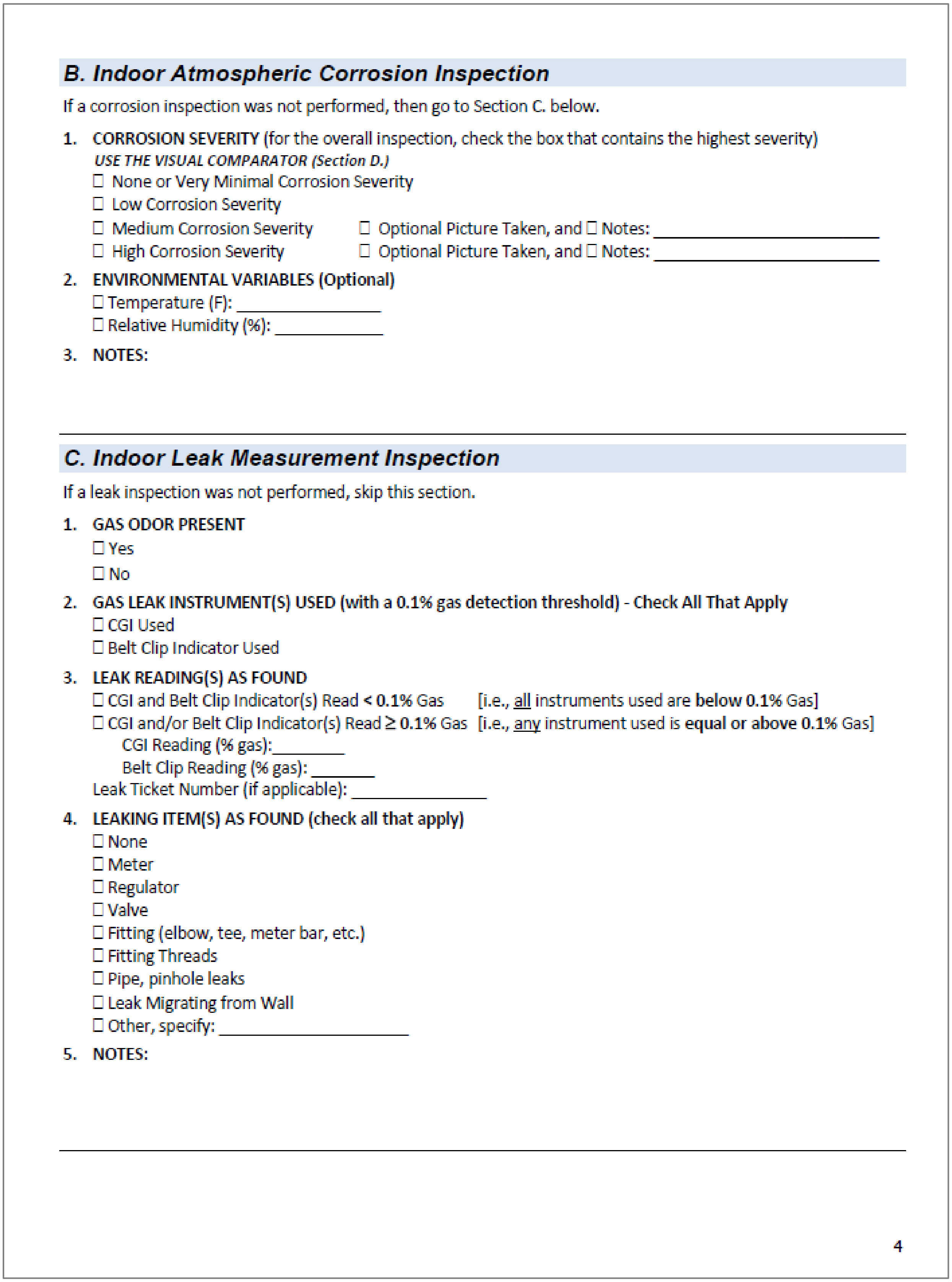
A. General Information for the Survey

1. **UTILITY NAME:** ____________________
2. **DATE OF INSPECTION (mm/dd/yy):** ____________________
3. **ADDRESS (street, city, and state)**
   Street: ____________________
   City: ____________________
   State: ____________________
4. **REASON FOR VISIT**
   ☐ Periodic Leak Survey/Corrosion Inspection
   ☐ Periodic Inspection (Other than Leak Survey/Corrosion Inspection)
   ☐ Service/Odor Call
   ☐ Meter read
   ☐ Meter change; turn Service ON/OFF
   ☐ Other, specify: ________________________________
5. **YEAR OF INSTALLATION**
   ☐ Known (year): __________
   ☐ Estimated: ____________
   ☐ Unknown
6. **SYSTEM INFORMATION**
   Pressure Regulator In Building? ☐ Yes ☐ No;
   If regulator is in building, specify system pressure (MAOP) upstream of regulator: ______________
   Inside Piping Utilization Pressure: ☐ Low Pressure (e.g., inches of water), or ☐ Other (specify):____________
   Pipe diameter(s) (inches): Upstream of regulator ____________ ; Downstream of regulator __________
7. **TYPE OF DWELLING**
   ☐ Single unit dwelling (e.g., single family residence)
   ☐ Multi-unit residence/dwelling (≥ 2 Family); Approximate number of dwelling units: _______________
   ☐ Other (specify, e.g., commercial, industrial, etc.): ________________
8. **METER LOCATION ATMOSPHERE: HEATING, VENTILATION, AIR CONDITIONING (check all that apply)**
   ☐ Heated space
   ☐ Air conditioned space
   ☐ Closed to the outside
   ☐ Vented to the outside
   ☐ Below grade, e.g. basement, crawl space, etc.
9. **METER LOCATION (general description)**
   ☐ Meter at/near POE
   ☐ Meter Room
   ☐ Meters in Multiple Remote Locations
   ☐ Other (specify, e.g., Room Set): ________________
10. **MATERIALS OF CONSTRUCTION**
    Check all that apply.

Piping	***Fittings***
☐ Steel: ☐ bare or ☐ coated/painted	☐ Steel: ☐ bare or ☐ coated/painted
☐ Copper	☐ Cast/malleable iron: ☐ bare or ☐ coated/painted

Meter/Regulator
☐ Steel: ☐ bare or ☐ coated/painted
☐ Aluminum: ☐ bare or ☐ coated/painted

3



B. Indoor Atmospheric Corrosion Inspection

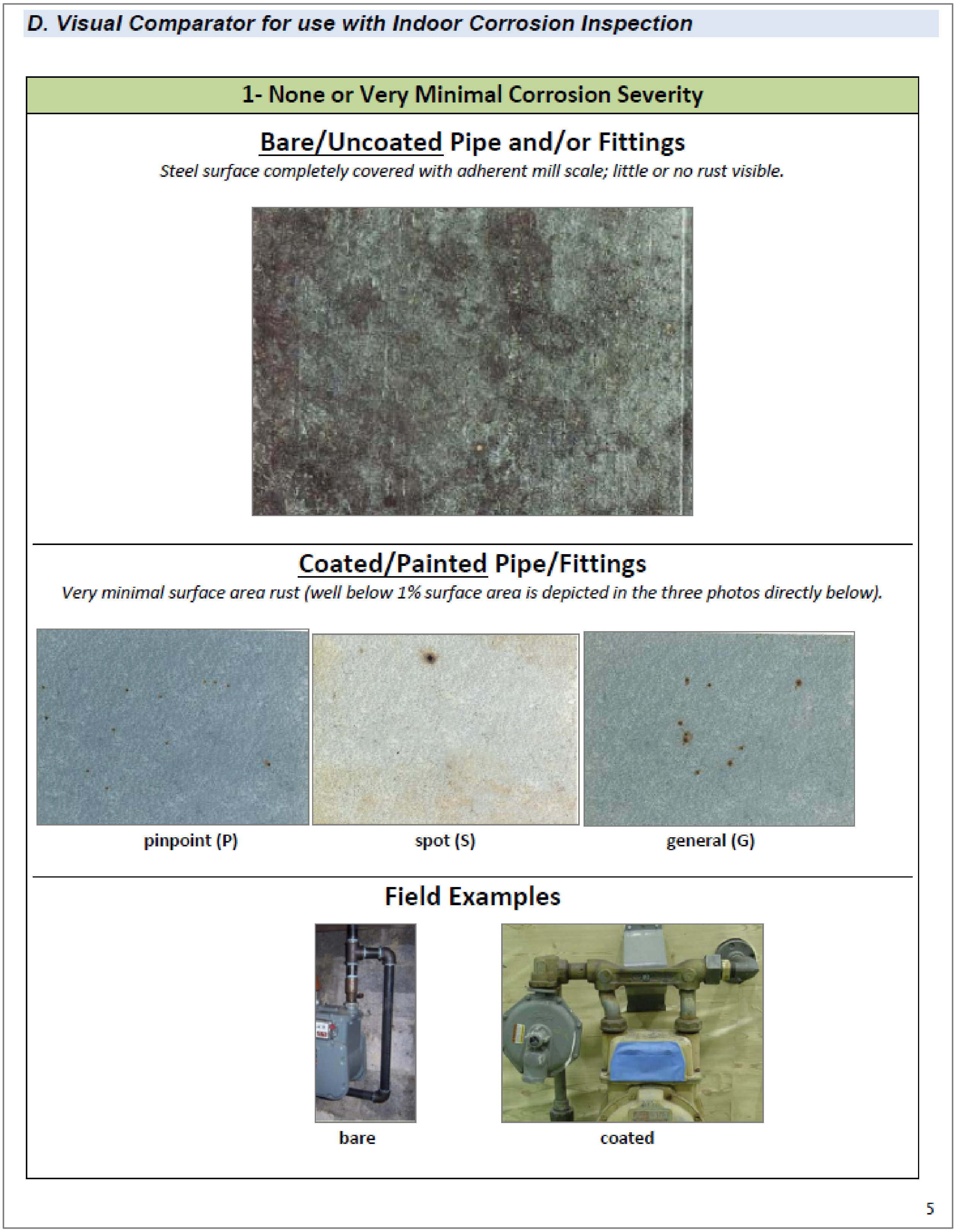
If a corrosion inspection was not performed, then go to Section C. below.

1. **CORROSION SEVERITY** (for the overall inspection, check the box that contains the highest severity)
   USE THE VISUAL COMPARATOR (Section D.)
   ☐ None or Very Minimal Corrosion Severity
   ☐ Low Corrosion Severity
   ☐ Medium Corrosion Severity ☐ Optional Picture Taken, and ☐ Notes: ____________________
   ☐ High Corrosion Severity ☐ Optional Picture Taken, and ☐ Notes: ____________________
2. **ENVIRONMENTAL VARIABLES (Optional)**
   ☐ Temperature (F): ____________
   ☐ Relative Humidity (%): __________
3. **NOTES:**

C. Indoor Leak Measurement Inspection

If a leak inspection was not performed, skip this section.

1. **GAS ODOR PRESENT**
   ☐ Yes
   ☐ No
2. **GAS LEAK INSTRUMENT(S) USED (with a 0.1% gas detection threshold) - Check All That Apply**
   ☐ CGI Used
   ☐ Belt Clip Indicator Used
3. **LEAK READING(S) AS FOUND**
   ☐ CGI and Belt Clip Indicator(s) Read **< 0.1%** Gas [i.e., <u>all</u> instruments used are **below 0.1%** Gas]
   ☐ CGI and/or Belt Clip Indicator(s) Read **≥ 0.1%** Gas [i.e., <u>any</u> instrument used is **equal or above 0.1%** Gas]
   CGI Reading (% gas):_______
   Belt Clip Reading (% gas): ______
   Leak Ticket Number (if applicable): ____________
4. **LEAKING ITEM(S) AS FOUND (check all that apply)**
   ☐ None
   ☐ Meter
   ☐ Regulator
   ☐ Valve
   ☐ Fitting (elbow, tee, meter bar, etc.)
   ☐ Fitting Threads
   ☐ Pipe, pinhole leaks
   ☐ Leak Migrating from Wall
   ☐ Other, specify: _______________
5. **NOTES:**



D. Visual Comparator for use with Indoor Corrosion Inspection

1- None or Very Minimal Corrosion Severity

Bare/Uncoated Pipe and/or Fittings

Steel surface completely covered with adherent mill scale; little or no rust visible.

Coated/Painted Pipe/Fittings

Very minimal surface area rust (well below 1% surface area is depicted in the three photos directly below).

pinpoint (P) spot (S) general (G)

Field Examples

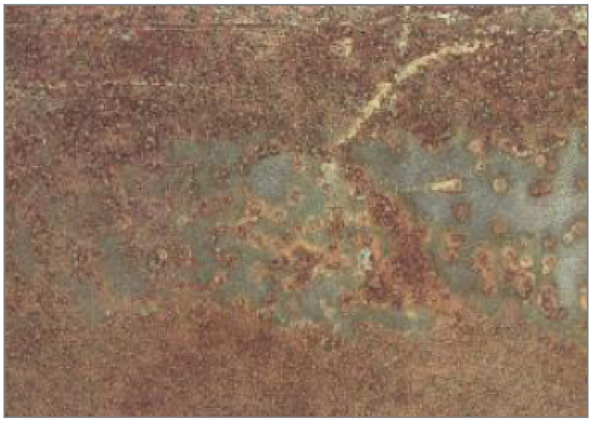
bare coated

5

2 - Low Corrosion Severity

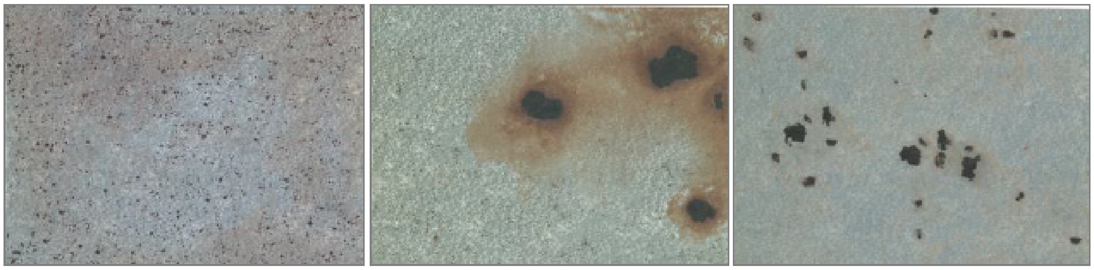
Bare/Uncoated Pipe and/or Fittings

Steel surface covered with both mill scale and rust.



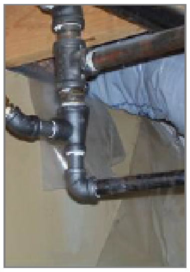
Coated/Painted Pipe/Fittings

Up to 3% surface area rust (3% surface area is depicted in the three photos directly below).



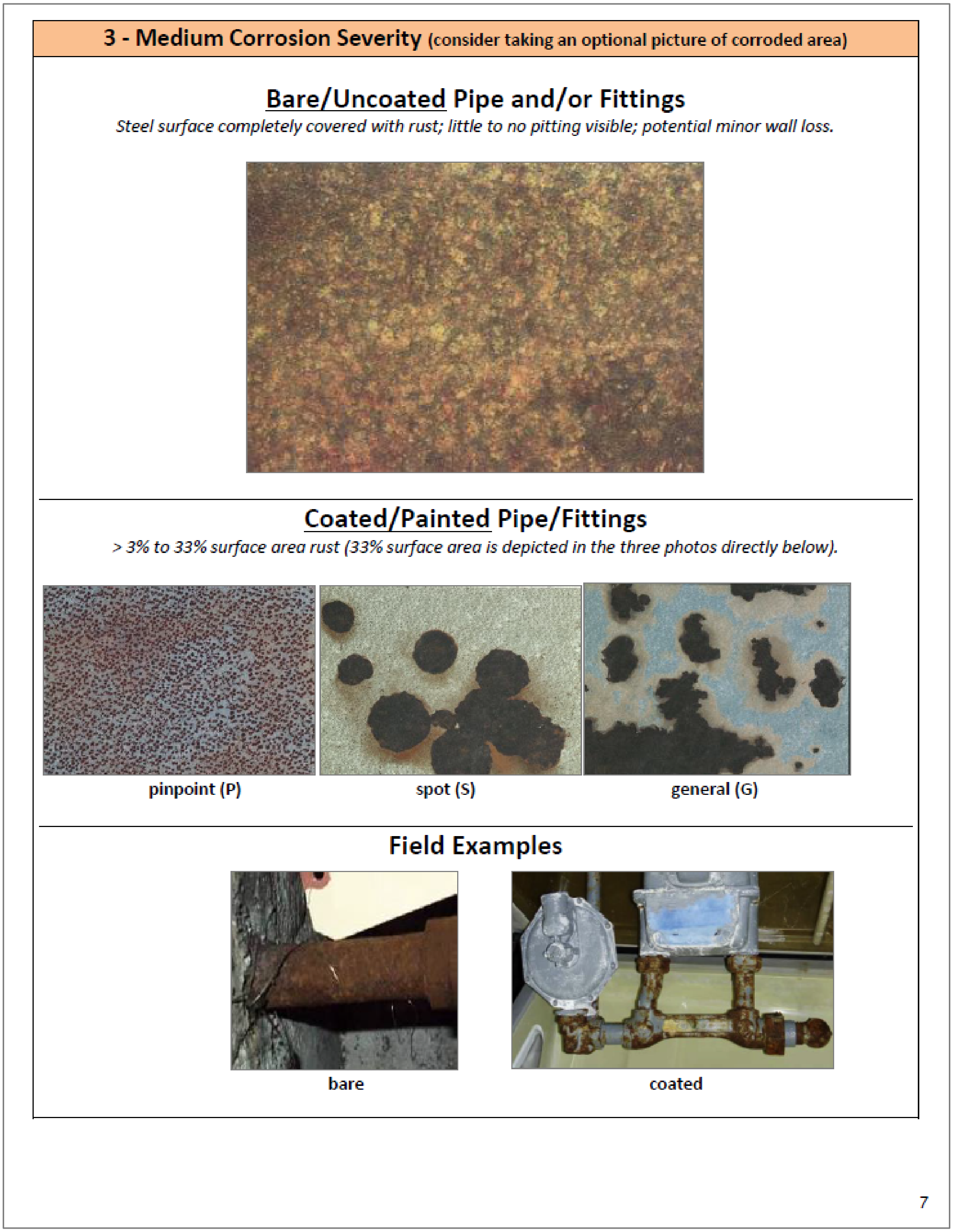
pinpoint (P) spot (S) general (G)

Field Examples



bare

coated



3 - Medium Corrosion Severity (consider taking an optional picture of corroded area)

Bare/Uncoated Pipe and/or Fittings

Steel surface completely covered with rust; little to no pitting visible; potential minor wall loss.

Coated/Painted Pipe/Fittings

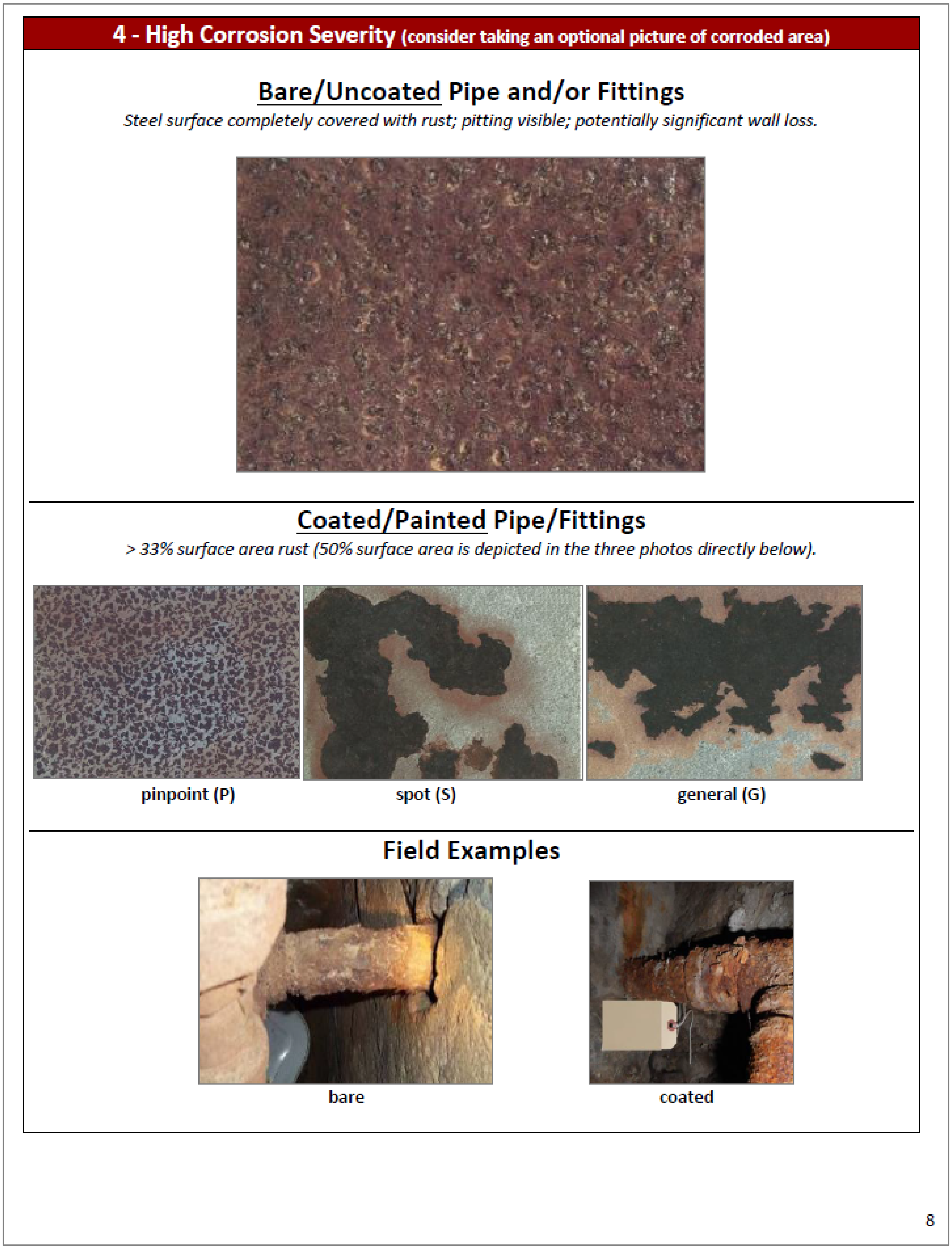
> 3% to 33% surface area rust (33% surface area is depicted in the three photos directly below).

pinpoint (P) | spot (S) | general (G)

Field Examples

bare | coated

7



4 - High Corrosion Severity (consider taking an optional picture of corroded area)

Bare/Uncoated Pipe and/or Fittings

Steel surface completely covered with rust; pitting visible; potentially significant wall loss.

Coated/Painted Pipe/Fittings

> 33% surface area rust (50% surface area is depicted in the three photos directly below).

pinpoint (P)

spot (S)

general (G)

Field Examples

bare

coated

8

End of Report