# Steam Piping Condition Assessments at Princeton University Using Ultrasonic Guided Wave Testing

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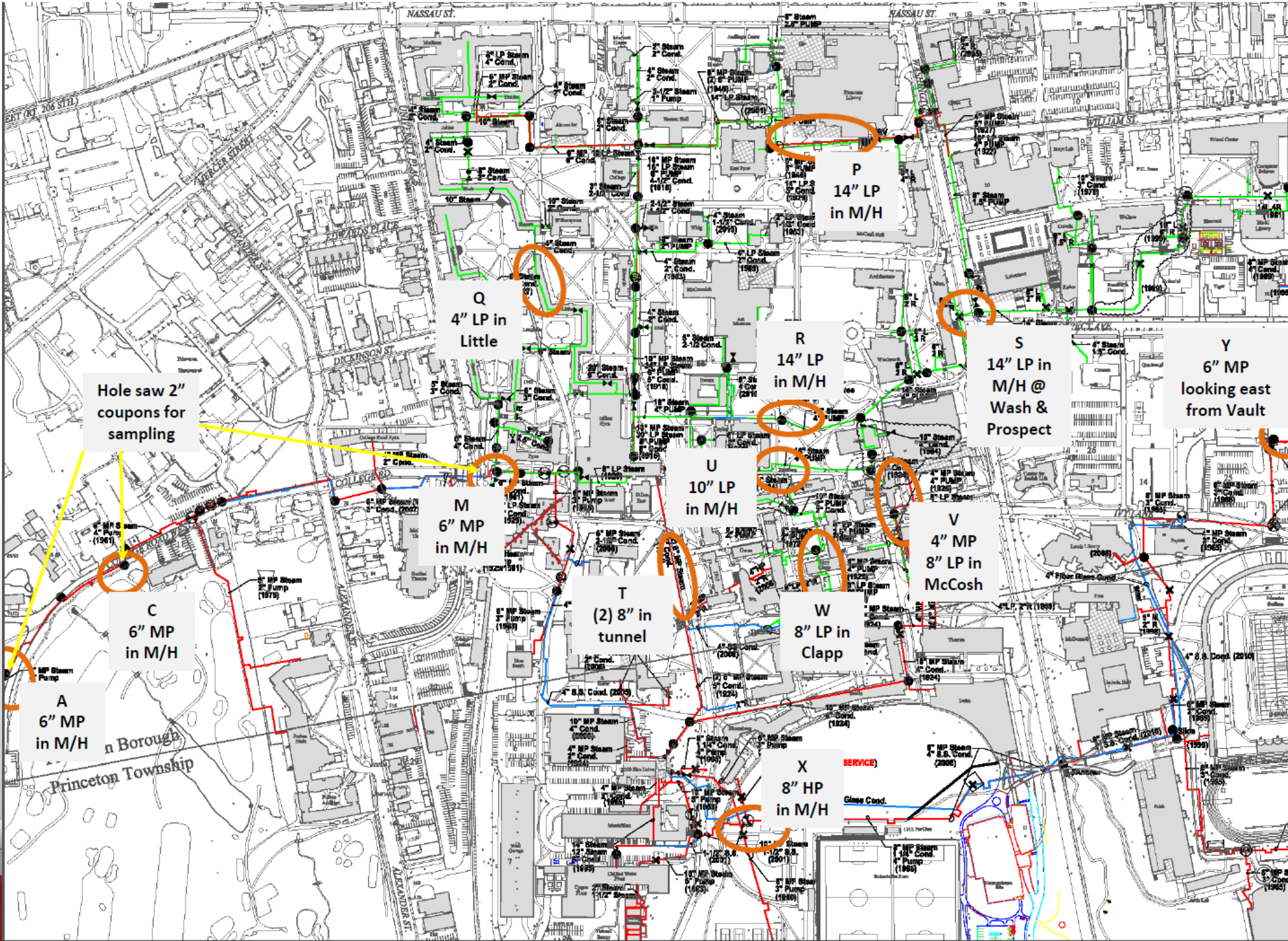
# Princeton District Steam System Background and Objectives

- 13 miles of operating steam distribution infrastructure anywhere from present-day to 100 years old.
  - Much of the system running below grade and inside of inaccessible tunnels.
- 200 PSI, superheated, 40,000 lbs./hour – 240,000 lbs./hour.
- Princeton Objectives and Strategy
  - What is the condition of the overall steam system for ongoing service?
  - Check steam lines, condensate lines, insulation, supports, anchors, expansion points, and tunnel /vault conditions.
  - Investigate locations known to be degraded due to prior failures.
  - Identify other areas of concern that should be monitored, repaired or replaced.

# Campus District Steam System



# Investigation Methods

- Review engineering records for: age, operating conditions, repair history, pipe size and specification if known
- Field walk-through in utility vaults and mechanical rooms
- Aerial thermal survey of entire district energy system
- Guided Wave Testing (GWT) and internal video of selected locations:
  - Variety representative of entire campus system age
  - Known failure locations

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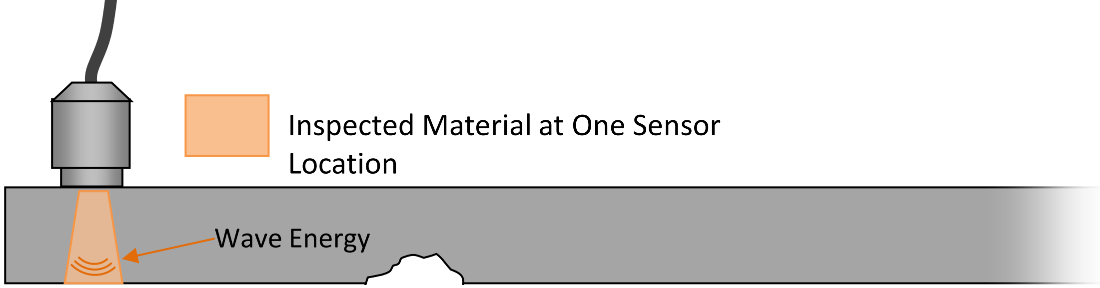
# Ultrasonic Guided Wave Testing (GWT) for Piping

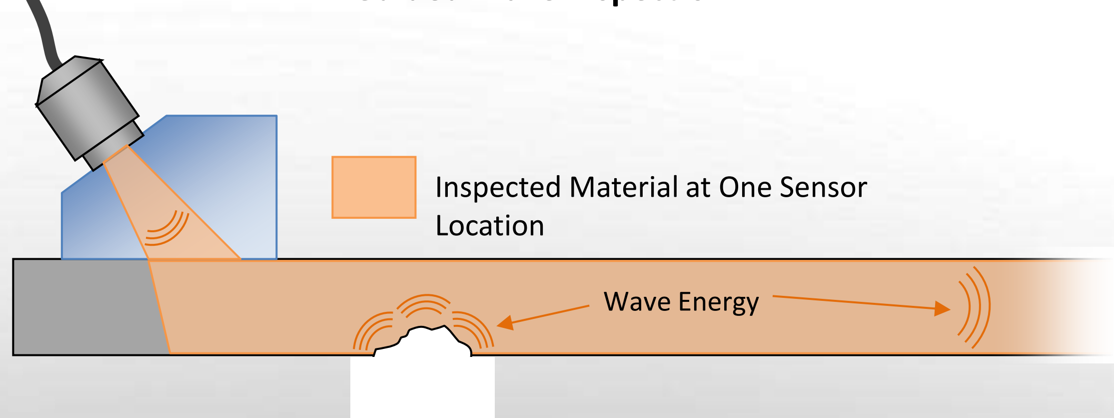
- Inspection of long lengths of pipe from a single probe position
- Allows for the screening of inaccessible piping from accessible areas minimizing the need for erecting scaffolding, removing insulation, etc.
- Scans the entire volume of pipe.
- Qualitative to semi-quantitative.
- Used to detect areas of interest for follow-up rather than just random sampling or manual scanning of thousands of feet of pipe.


# Ultrasonic Guided Wave Testing (GWT)

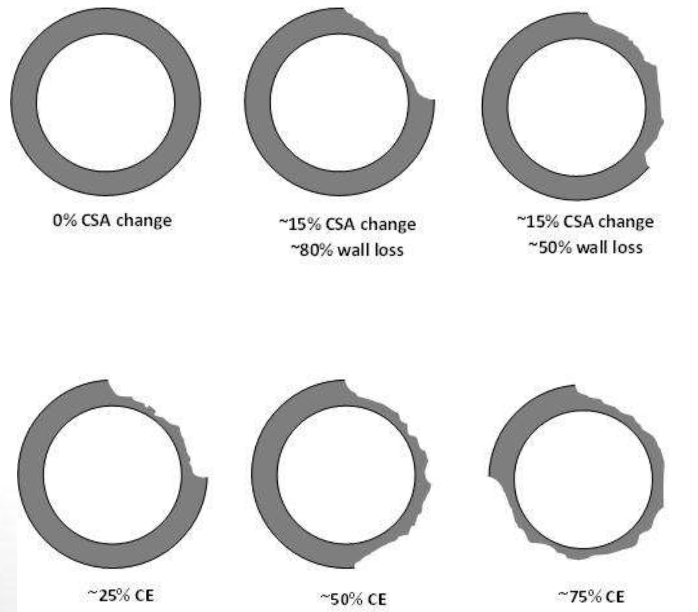
**Traditional UT Thickness Measurement**




**Guided Wave Inspection**




## Cross Sectional Area and Circumferential Extent

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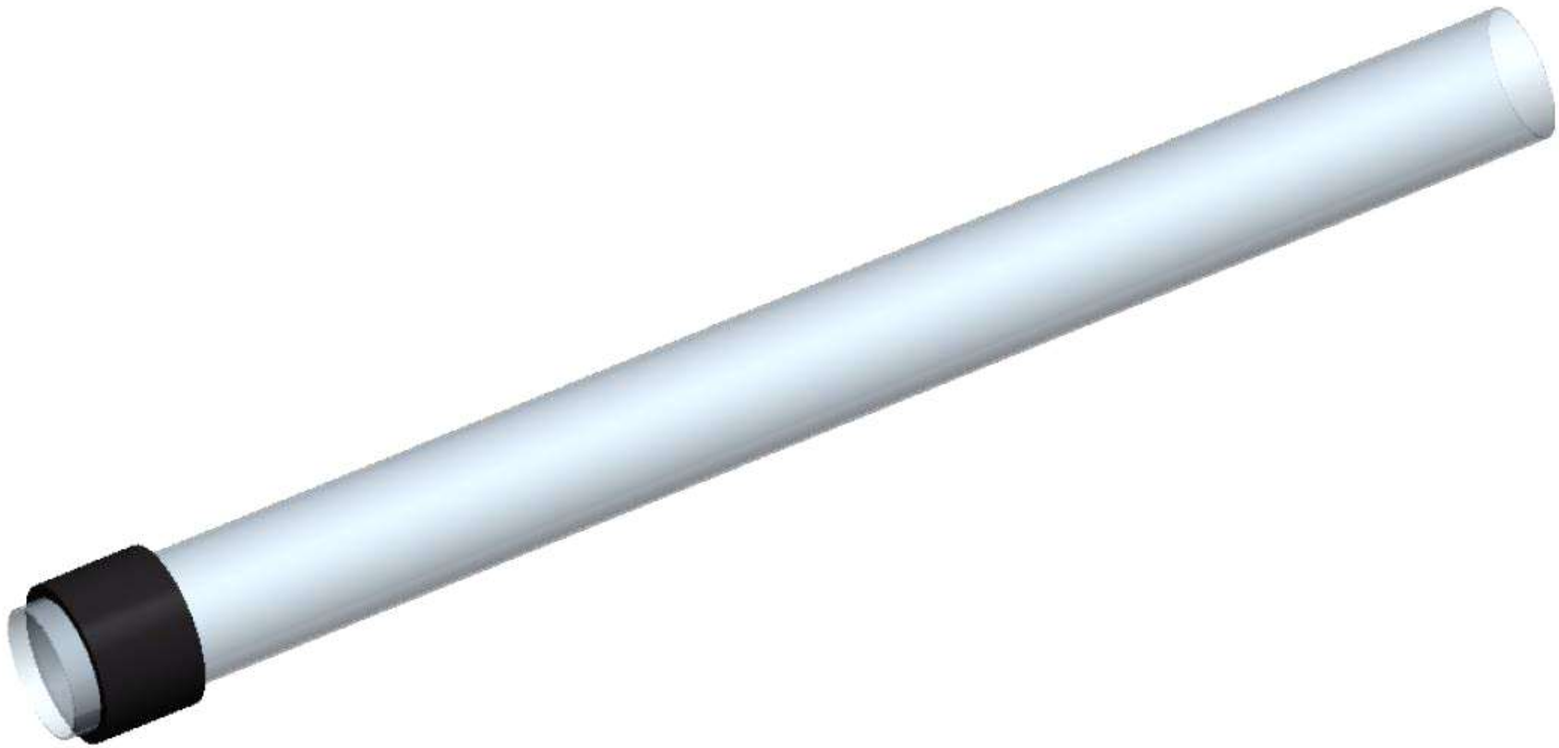
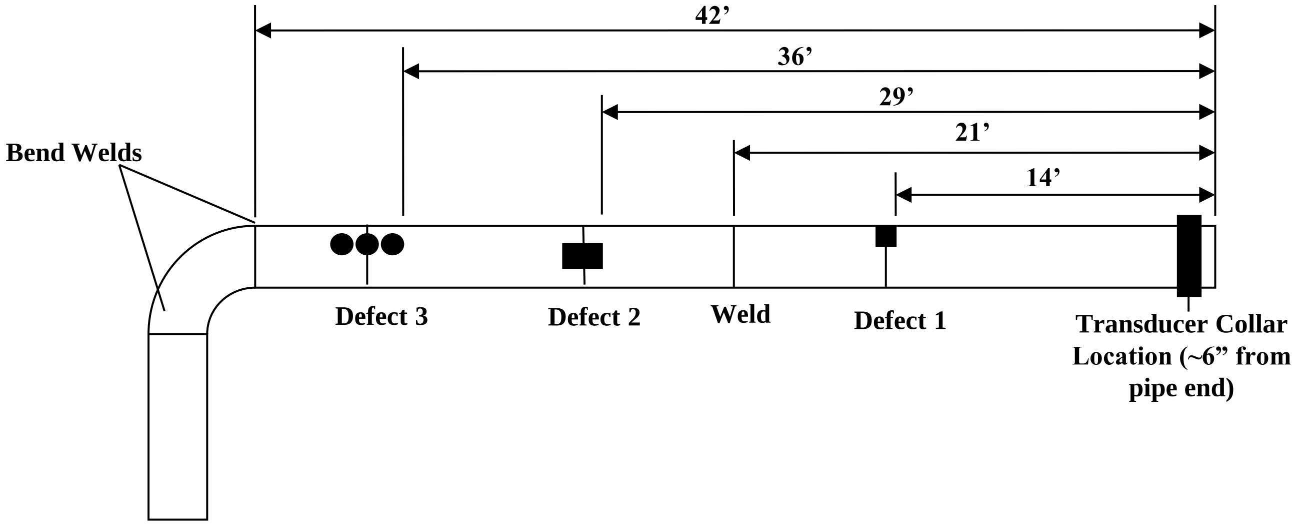
# Guided Wave Pipe Inspection Concept



# GWT Example Result




**Defect 1 - 0°**

~3”x3” Blend Out

50% Max Wall Loss

**Defect 2 - 270°**

~4”x4” Blend Out

50% Max Wall Loss

**Defect 3 - 315°**

Three Flat Bottom Holes

1” Diameter, Depth=60%

Spacing between holes = 1 ft.

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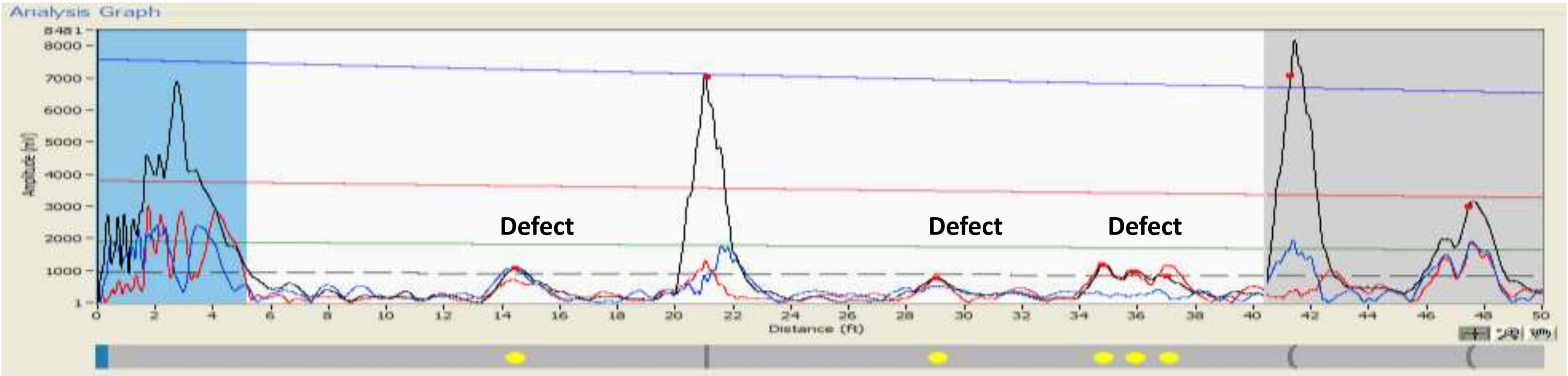
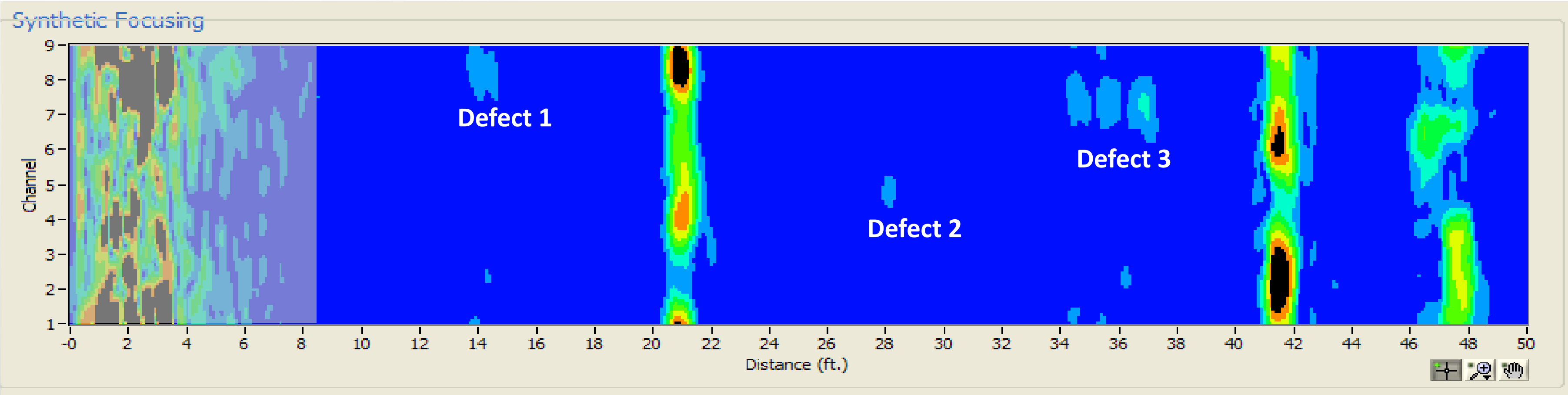
# GWT Example Result

A-Scan




"C-Scan"

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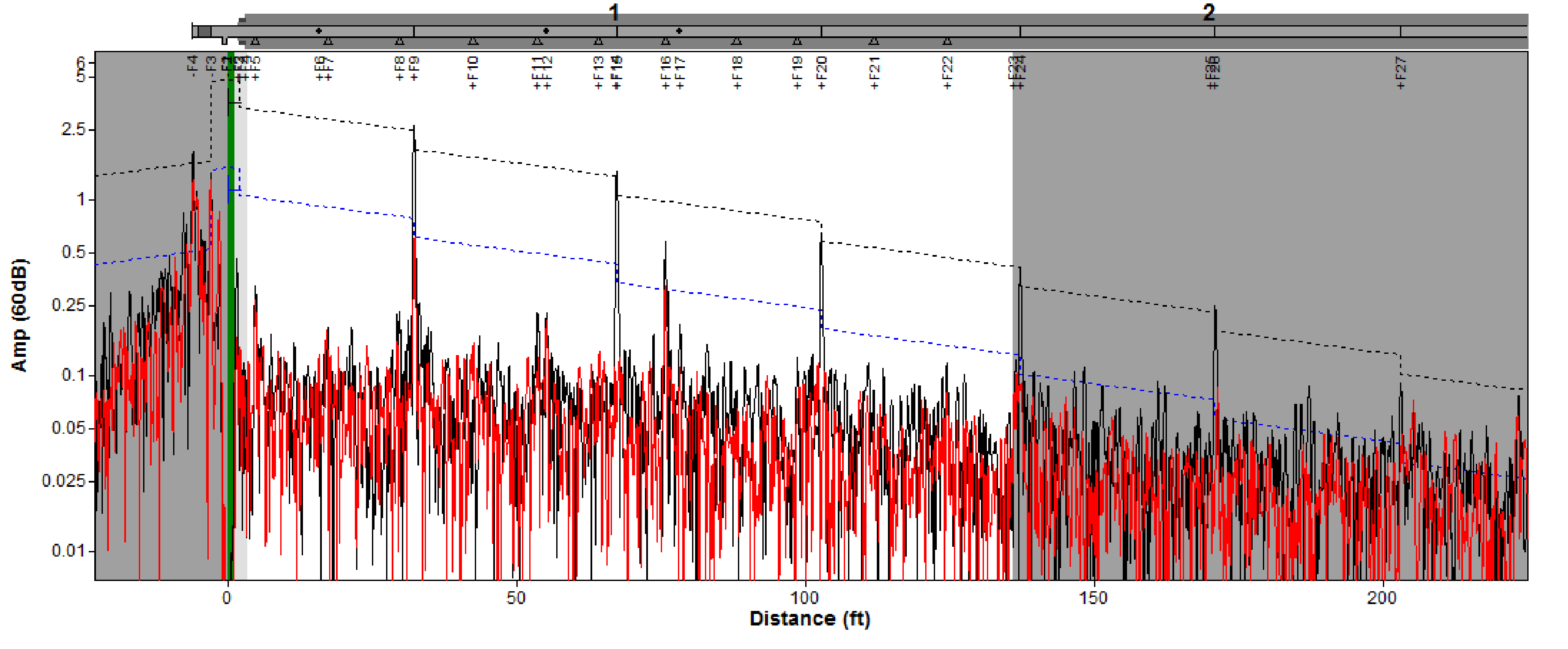
# Princeton GWT Sample File




Sample GWT data filed from Princeton Steam Line showing good penetration with ~135 ft. of coverage in one direction.

# Princeton GWT Assessment Strategy

- Incorporate the use of GWT to screen inaccessible tunnel piping from accessible manhole test locations.
- Conduct conventional UT/VT direct examinations on exposed sections inside the manholes to provide quantifiable information
- Test locations selected from risk ranking of piping (year of construction, consequence of failure, likelihood of degradation, etc.)
- Planning and coordination amongst multiple crews (steam piping shutdown, insulation removal, inspection team, etc.)

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# Princeton GWT Summary

- First mobilization in June, 2013 to inspect various lines from inside 7 manholes.
- Based on inspection findings, one line (the "graduate school line") was targeted for additional inspections.
- Second mobilization in October, 2013 to further inspect the graduate school line from inside 9 manholes.
- A total of 1,268 ft. of pipe was screened using GWT over two days of testing.
- Comprehensive UT and visual exams were performed at all test locations.

# Photos

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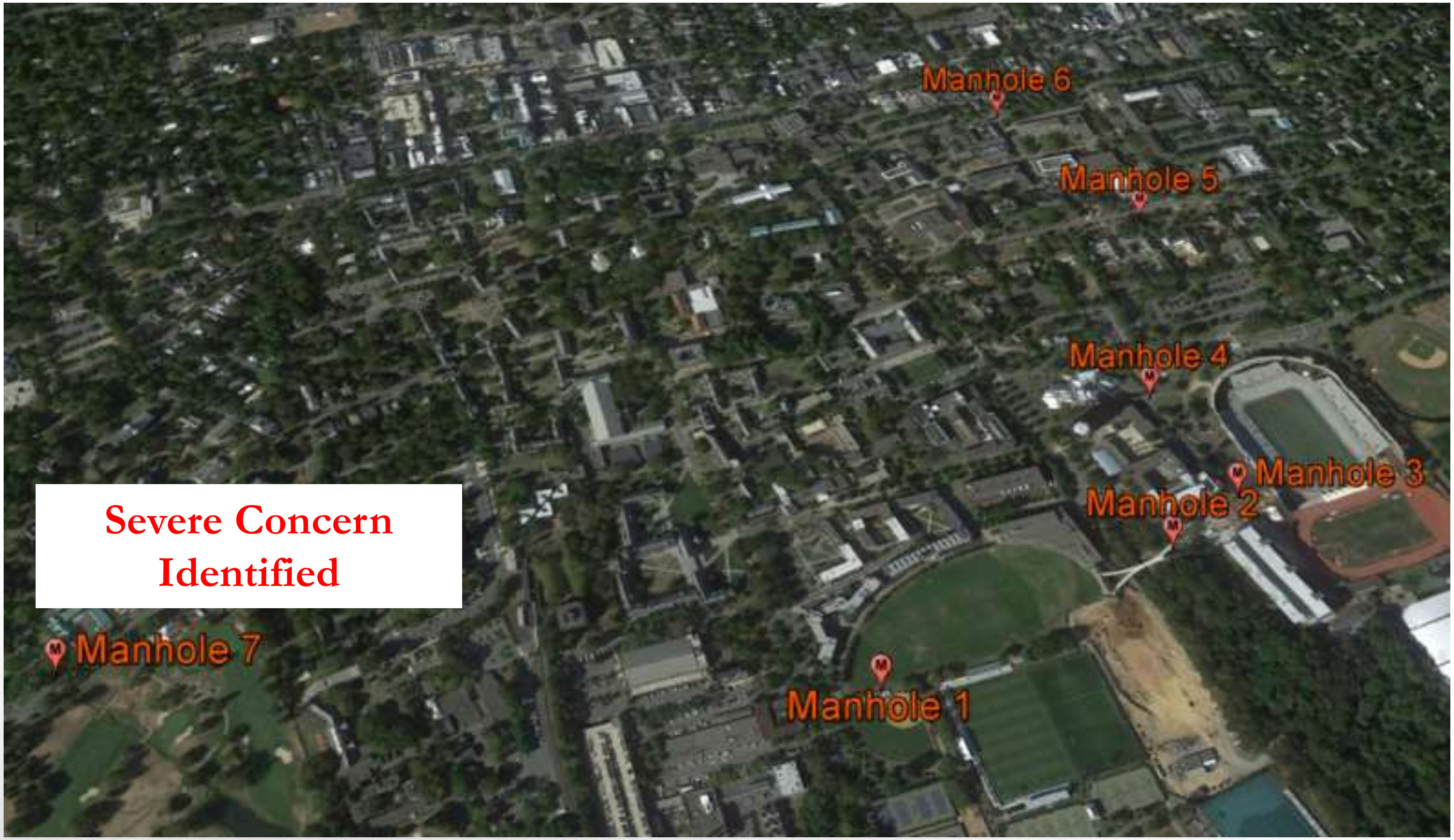
# Mobilization 1 Test Locations




- GWT and UT conducted inside 5 manholes to screen 671 ft. of pipe. Grad School Line (Item 21/Manhole 7) targeted for more inspections based on findings.

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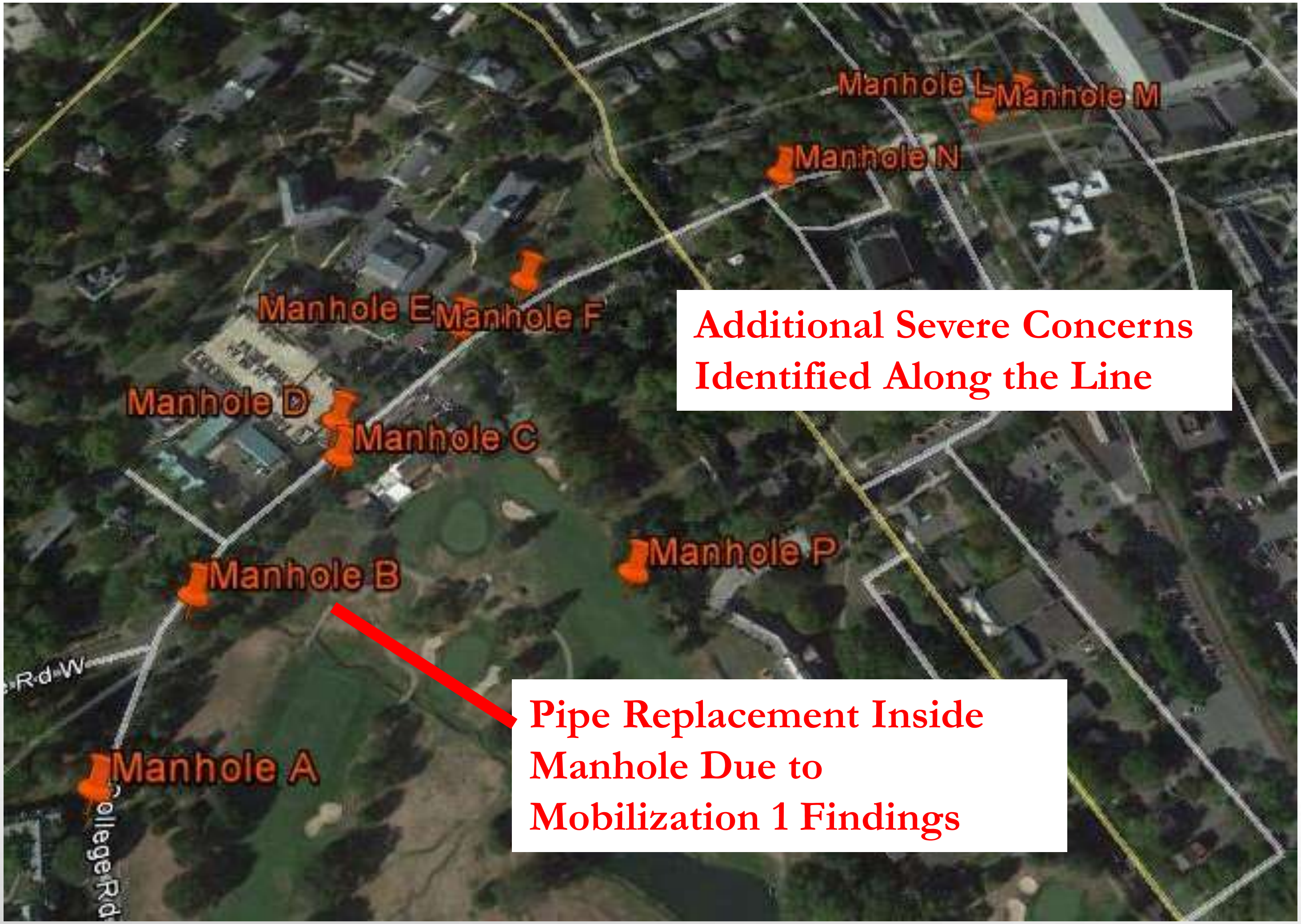
# Mobilization 2 Test Locations




- GWT and UT conducted inside 9 manholes to screen 597 ft. of pipe.

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# Pipe Replacement from Manhole B

Based on the Mobilization 1 findings, a section of pipe was cut out and replaced in inside Manhole B. The cut out section was sent to SI's Material Research Center for further "destructive" analysis.

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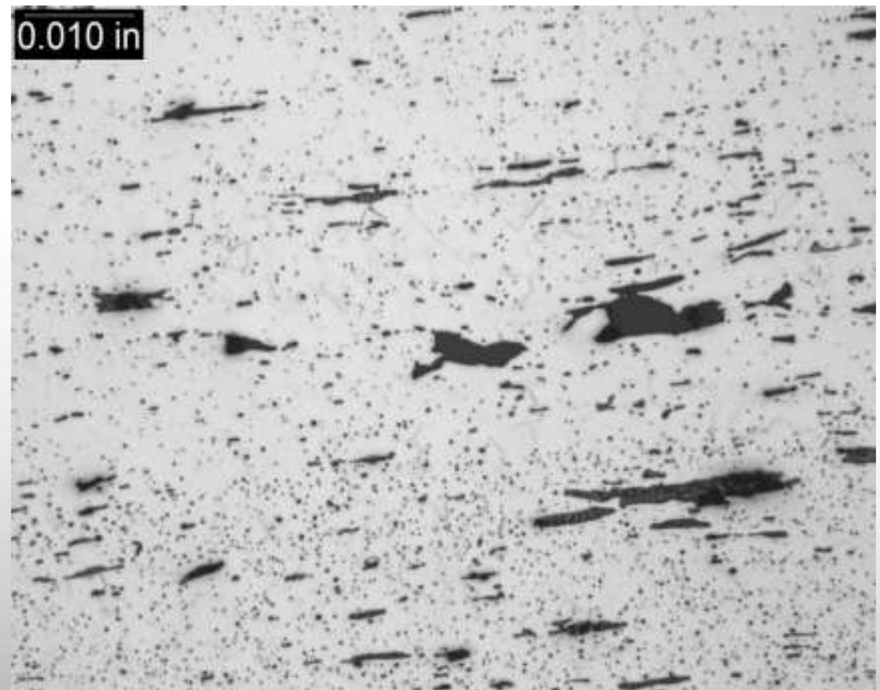
# Key Findings from Metallurgical Analysis

- The material is very "dirty" steel with a large amount of non-metallic inclusions, questionable chemistry, and relatively low hardness.
- Internal corrosion (36% wall loss) was present and concentrated to the region of the pipe near the pulled bend, likely the result of steam condensation collecting at a low point at the start of the bend.
- The corrosion is localized in nature, but it does not appear to be preferentially attacking any specific microstructural features.
- It cannot presently be determined why the corrosion is affecting localized areas, but a possible explanation might be that these areas contained inclusions near to or breaching the ID surface.

# 6 Inch Pipe Internal Corrosion

Un-etched cross-section of the ID corrosion observed on the 6 inch pipe segment.  The material contains a high concentration of non-metallic inclusions

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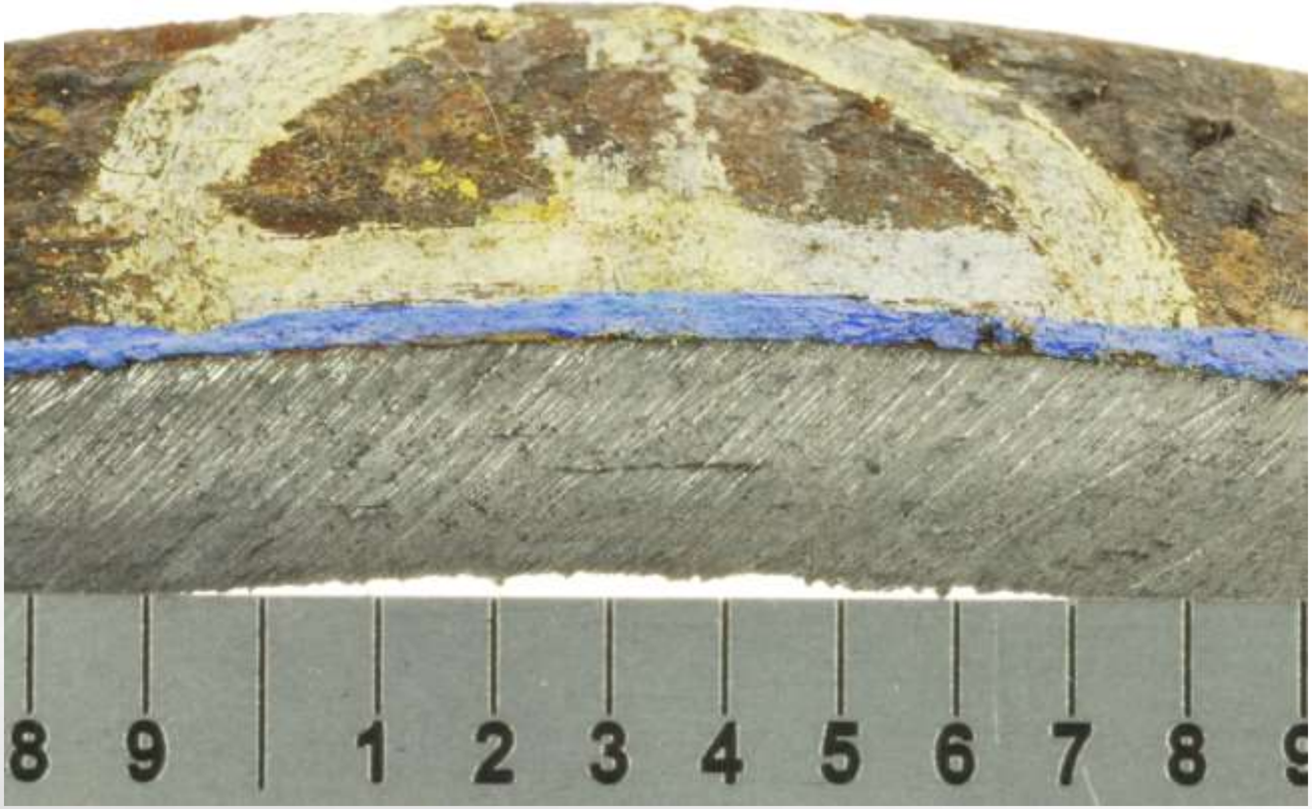
# 6 Inch Pipe Mid-wall Inclusion




This macro inclusion was detected with UT and confirmed with metallography.

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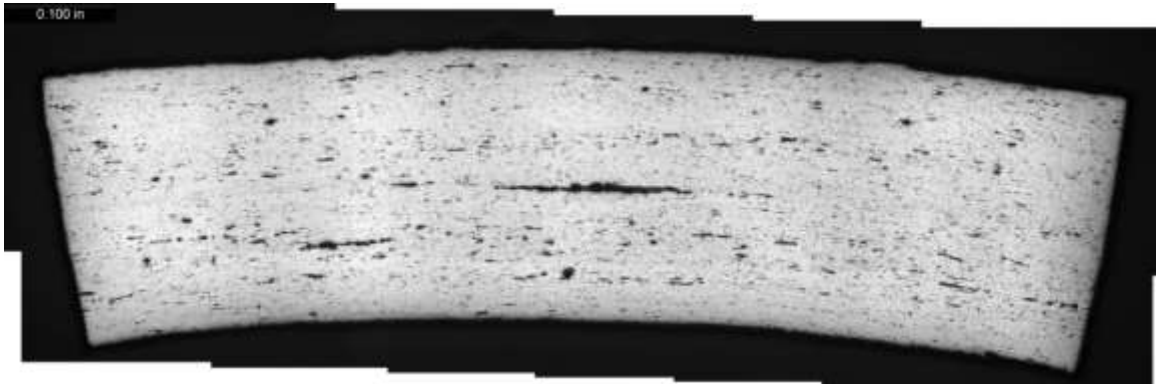
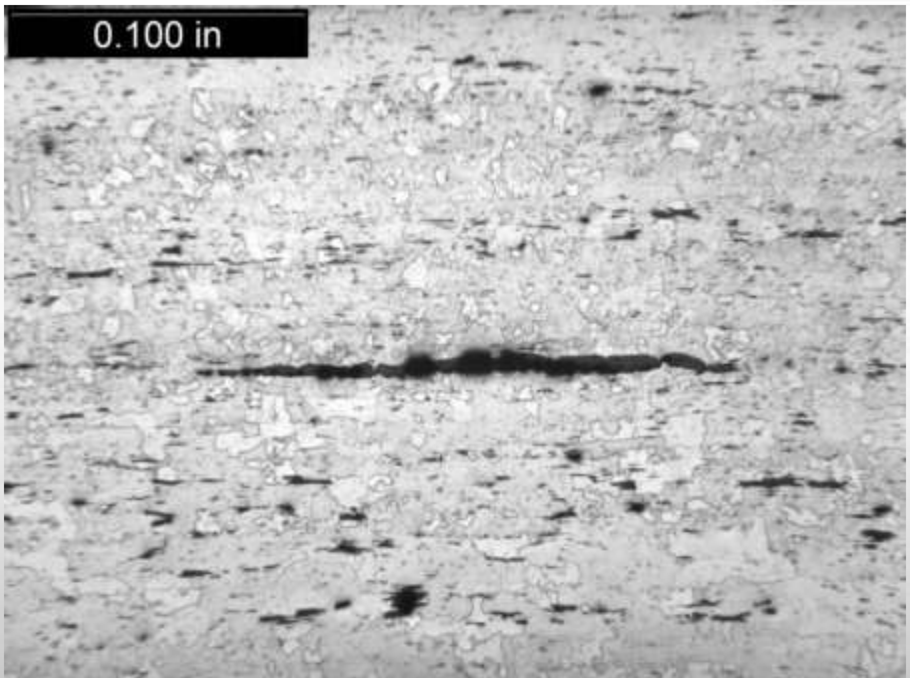
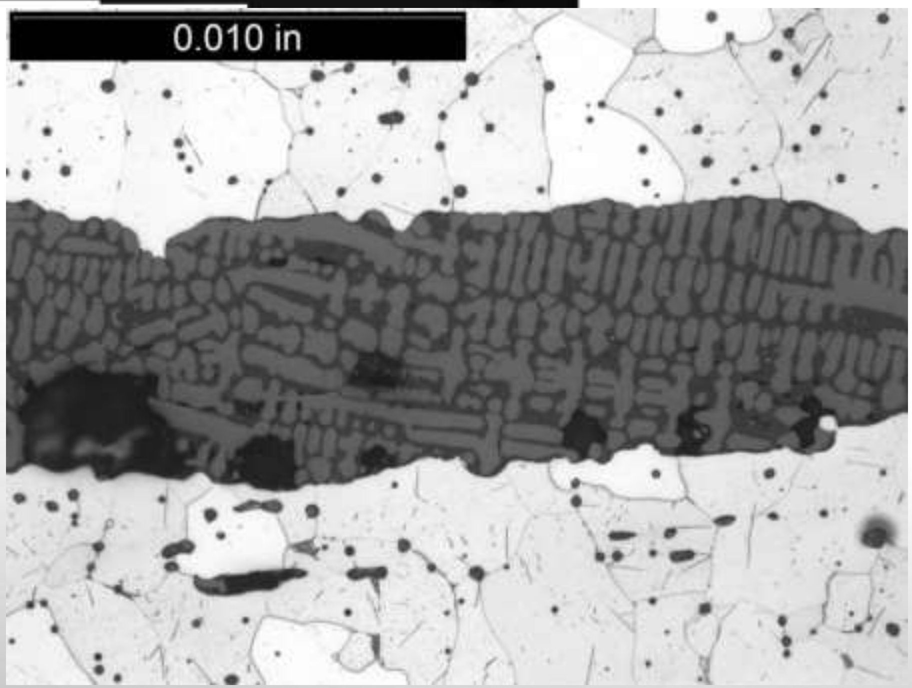
# 6 Inch Pipe Mid-wall Inclusion



# Recent Inspection Activities

- Steam shut-down - June 5th, 2014
- GWT inspections were completed from an additional 10 test locations
  - Manhole selection based on risk ranking parameters (consequence of failure, previous inspection data, likelihood of corrosion).
  - Coupons removed for metallurgical analysis from several other sections of the grad school line selected from the last round of inspection data to determine if the inclusions are localized or present throughout the system.

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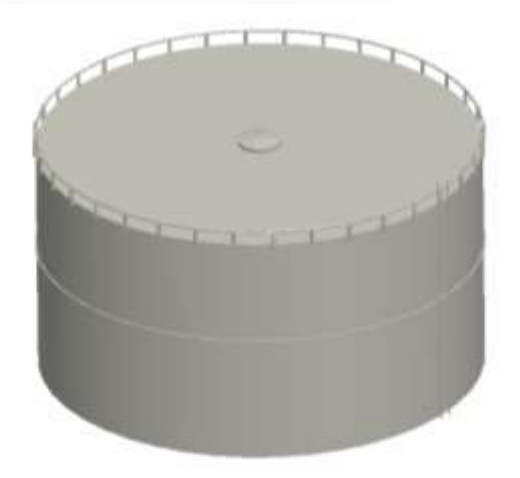
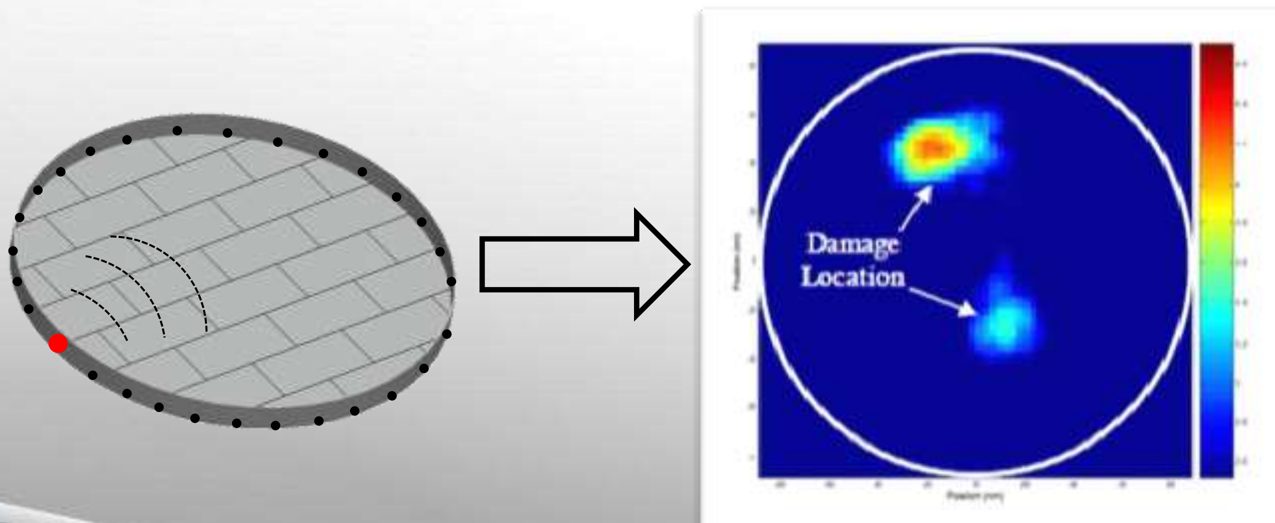
# Future Activities

- Further mechanical testing is being performed on the existing cutout section to determine material properties for comparison against design/performance specifications.
- Remediation/replacement plan development considerations for the graduate school line pending metallurgical analysis results.
- Considering the use of GWT for long range inspection/monitoring of approximately 50 storage tanks at Princeton.





# Summary

- Assessments have been completed on the steam plant piping system at Princeton which have revealed some areas that need corrective work and further areas that should be investigated to determine their condition.
- The key driver of the assessment strategy was the use of ultrasonic guided wave testing to provide long range screening of inaccessible tunnel piping from accessible manhole test locations.
- Previous inspection data and risk ranking of piping segments is driving future inspection activities.
- The use of GWT is being considered for aging storage tank inspection/monitoring.

# Questions?

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