SI – DRESDEN SERVICE WATER ENGINEERING EVALUATIONS AND G-Scan™ INSPECTIONS

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ABSTRACT

In 2005, Structural Integrity Associates, Inc. (SI) assisted Dresden nuclear station in locating and characterizing a leak in a 54 inch buried service water pipe using long range guided wave ultrasonics (G-Scan™) inspection and engineering evaluations. The SI support to Dresden permitted the magnitude of degradation that had produced the leak to be understood and permitted structural integrity assessments of the piping to be made that allowed the plant to continue to operate safely until one of the two Dresden units was scheduled for an outage. At that time, both Dresden units were brought down, the line was dewatered, and a non-metallic structural repair was applied to the leak location as well to other locations with lesser degradation that had been detected during the original inspection. An overview of the G-Scan™ method and details of the subject inspection and analysis are discussed.

BACKGROUND

Dresden Nuclear Power Station is located near the city of Morris, IL, about 60 miles southwest of Chicago, adjacent to the confluence of the Kankakee and Des Plaines Rivers. Those two rivers combine to form the Illinois River at the Dresden Lock & Dam. Dresden Units 2 and 3 went into service in 1970 and 1971, respectively. Both units are GE boiling water reactors (BWR 3s), designed for 715 MWe; uprated to 834 MWe at the time of initial commercial operation. Unit 2 was uprated to 912 MWe in 2001, with Unit 3 to follow in 2002.

THE EVENT

In September 2005, Dresden discovered a leak in a buried water line. Both units were running at full power at the time, with no indications of any difficulties. The leak was detected by an influx of water to the turbine building. Initial tests performed by the site determined that the leak was in a buried 54" balance of plant (BOP), non-safety related service water header that is common to Dresden Units 2 and 3. The estimated magnitude of the leak was approximately 20 gpm.

The location of the leak was believed to be between the radwaste building and the turbine building where the pipe is encased in a series of concrete vaults, however, the exact location of the leak (or whether the leakage was occurring from several sites in the service water header) was unknown. The magnitude of degradation at and near the leak site was also unknown.

Immediate Impacts
The site needed to determine the structural integrity of the pipe – that is, was the pipe structurally sound, even though there was a breach, apparently small, in the pressure boundary. Further, inspection by visual methods or conventional ultrasonics and any repair would require that the line be dewatered to permit personnel access. Shut down of that common header to the two unit plant required that both units be shut down. Lost generating capacity would be of the order of 1800 MWe and approximately $2,000,000 per day of downtime.

Longer Term Impact
The presence of this leak had other impacts, primarily questions on the condition of other headers (including safety related headers) and other buried pipe.

Credibility with the NRC on the condition of safety related buried pipe and other safety related lines also became a consideration at Dresden and at other nuclear facilities because of the presence of the leak.

Candidate Approaches
Buried piping assessment methods commonly used in the nuclear industries were unlikely to be very helpful. The initial determination by the plant was that the only safe way to inspect this line was from the inside. In Line Inspection (ILI) is usually not feasible for power plant applications (pitch and catch stations are needed; it was clearly not feasible for this line), it is expensive (not a real consideration in this case), it requires the line to be clean (the level of internal cleanliness of this line was completely unknown), and ILI also presented risks relative to the potential for inflicting damage to other subsurface systems.

As a result, ILI and other commonly used direct examination methods were disqualified. The plant decided to use G-Scan™, long range guided wave ultrasonic examination to attempt to locate the leak, size the degradation in the vicinity of the leak, and make decisions regarding the future course of action, including timing and design of repairs, based upon the G-Scan results. The primary advantage offered by the G-Scan technology was the ability to interrogate the buried line from the inside of the building without dewatering the line and taking both units off-line.

BURIED PIPING ISSUES

This line was typical of raw water lines at virtually all nuclear sites. Service water, other raw water, and buried systems at nuclear sites typically consist of miles of pipe, both above ground and buried, that experience a wide variety of flow conditions. Figure 1 is a simplified sketch of the Dresden service water system. Those piping systems also include hundreds of heat exchangers and valves.

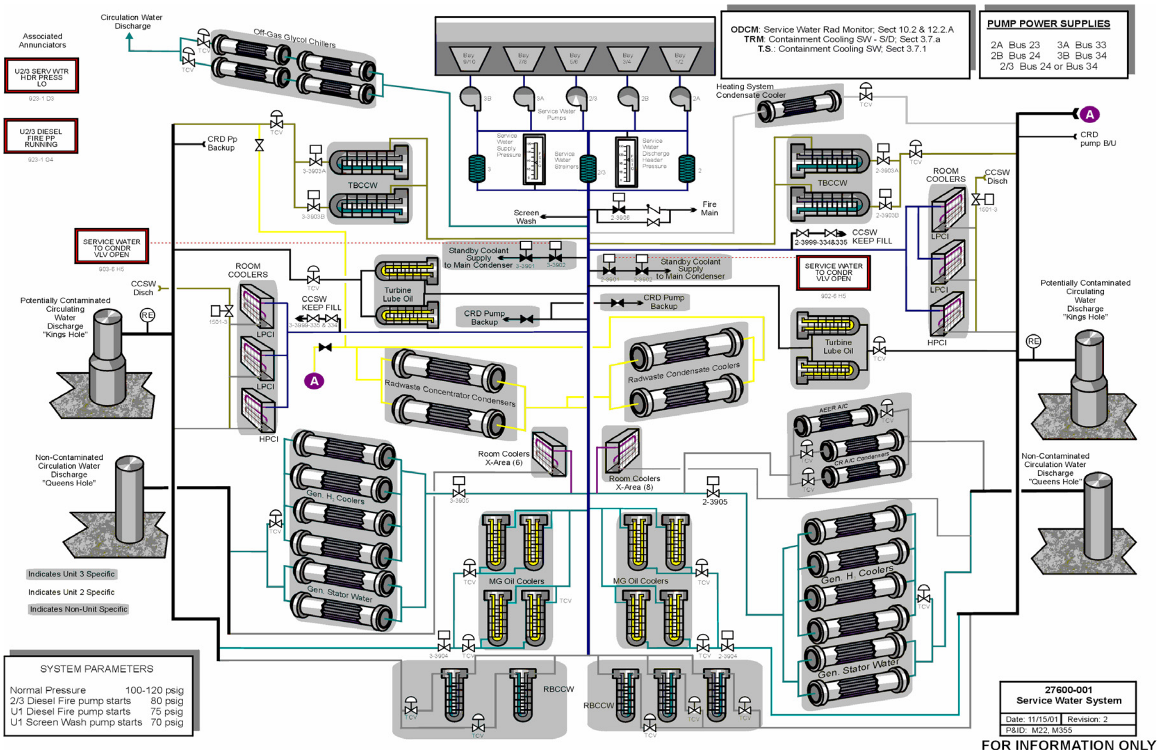

Figure 1. Simplified Sketch of Dresden Service Water System

The EPRI Service Water Piping Guideline [EPRI 1010059] provides guidance on the available methods for assessing and mitigating failures in service water piping. The objectives of that guideline are to help utility personnel to:

- Improve piping reliability
- Provide background information required to develop programs for inspection, management of piping degradation, corrosion mitigation, and repairs and replacements
- *Manage* service water and buried piping degradation
- Provide run/repair/replace criteria
- Make intelligent selections for repairs and replacements

The service water piping guideline also recognized that because of the diversity of service water system designs, water sources, materials, etc. between plants and the variety of flow and degradation conditions within a single plant, that any useful guideline:

- Can't be prescriptive, and that
- Different systems will have different answers in terms of inspections, mitigation, responses to pinhole leaks,

Degradation

Degradation of nuclear plant raw water and buried systems most often results in pinhole leaks from generalized thinning, localized thinning and cracking. Potentially operative degradation modes are corrosion, fatigue, and cavitation

For service water systems and other raw water and buried piping systems, corrosion is by far the predominant degradation mechanism. For buried piping, corrosion from both the ID surface (at least for systems containing water) as well as from the OD can be operative. Forms of corrosion that must be considered are general corrosion (both ID & OD), tuberculation (ID consideration only), localized abiotic corrosion (pitting and crevice corrosion; ID & OD), microbiologically influenced corrosion (MIC; ID & OD), galvanic attack (ID & OD), and dealloying (confined to copper alloys and cast iron; ID & OD), and stress corrosion cracking (SCC; ID & OD).

Accumulated corrosion damage that manifests itself in leaks can be described by the typical "bathtub curve" as shown in Figure 2. That curve, whether derived after the fact from a plant's leak history or from a predictive assessment that uses probabilistic methods (e.g., Monte Carlo) to combine the distribution of corrosion rates (both general and localized), variations in wall thickness (both random and from different pipe sizes in the system), and the effects of water treatments (or OD mitigation approaches such as cathodic protection for soil side degradation) provides a clear illustration that a very low number of leaks is expected for early life, even up to a 40 year design life, but that as exposure time increases, the number of leaks to be expected will increase dramatically.

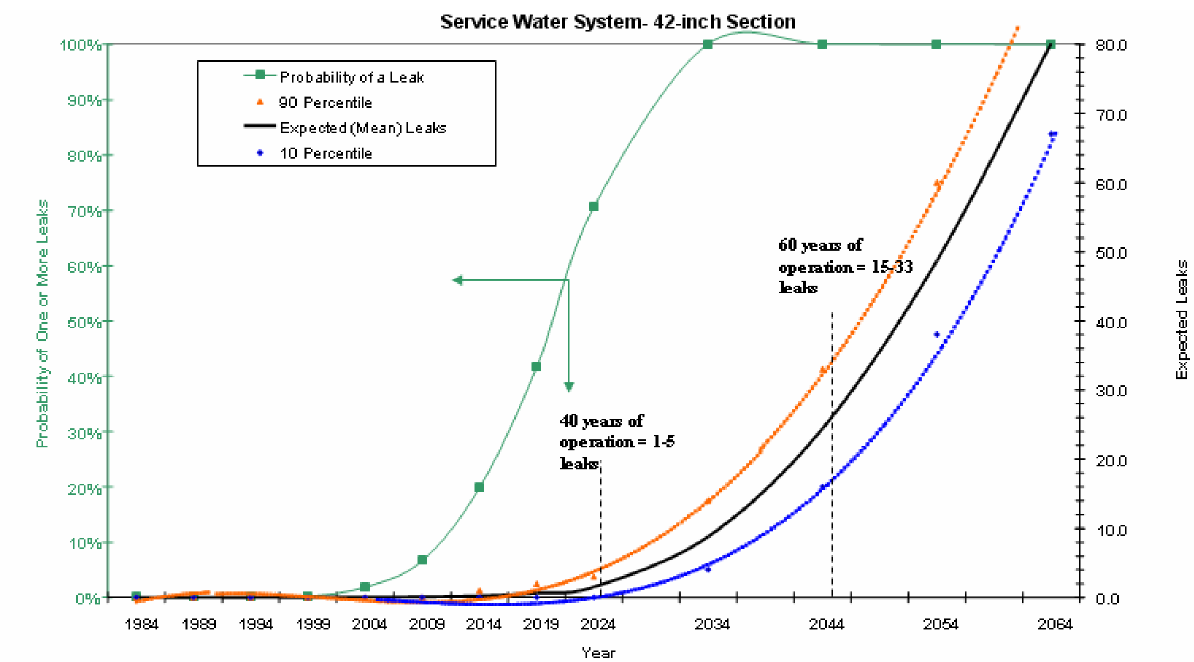

Figure 2. Predicted Leak Evolution. Example

Inspection

Volumetric inspection of system piping can provide a definitive demonstration of the overall condition of the system piping (e.g., where along the bathtub curve that the plant actually is) as well as detailed information on the condition of degraded areas to permit determinations of run vs. repair vs. replace decisions. Unfortunately, for service water systems and for buried piping systems, the system size often makes the use of commonly used methods such as point-to-point ultrasonic thickness determinations of minimal value because of the very limited sample size, often far less than 1% of the system area, that can be inspected. For buried systems, accessibility is of course limited, which generally disqualifies contact methods or methods that require close proximity to the piping material to interrogate a useful area (several square inches at a time). SI and others have found that long range guided wave ultrasonic methods provide an effective tool for screening level inspections of piping systems, including systems with limited access, examination under insulation or within concrete encasements, etc.

SI uses a torsional guided wave system that is the third generation GUL System developed by the Imperial College of the UK and manufactured by *Guided Ultrasonics LTD*. The collar contains dozens to hundreds of transducers/receivers (based upon the pipe size) arranged circumferentially. The torsional waves are computer generated at a continuous range of frequencies from 16 to 30 KHz. Waves propagate along the length of the pipe, producing reflections from symmetric or asymmetric features (Figure 5). Couplant is not required and the inspection can generally be conducted through a paint coating.

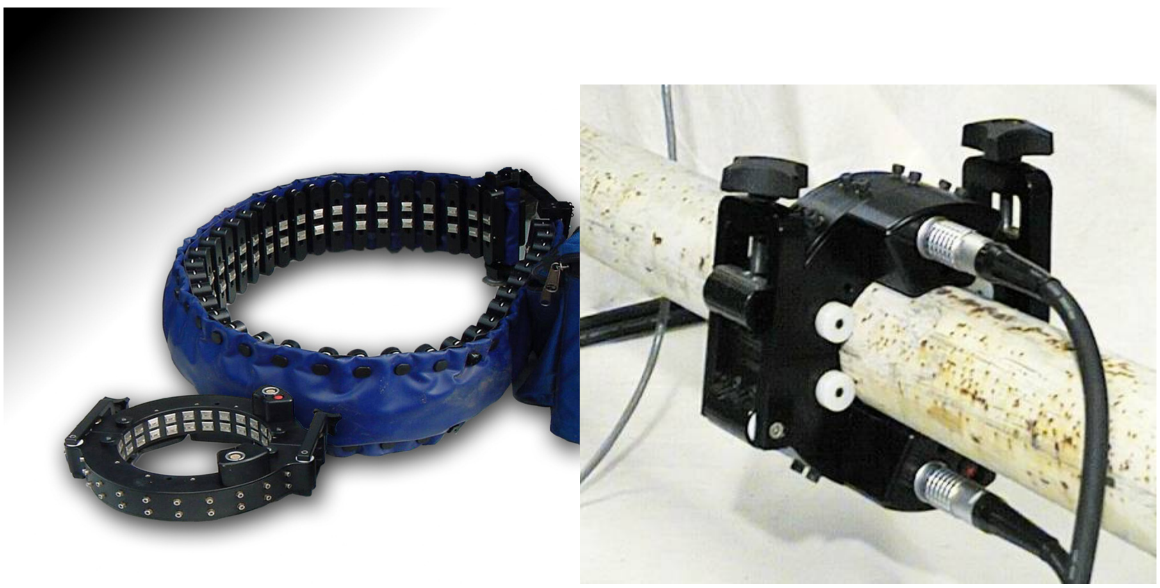

Figure 3. G-Scan™ Collars

Examination of Buried Pipe from Above Ground

Examination of Insulated Pipe

Figure 4. Typical G-Scan Installations

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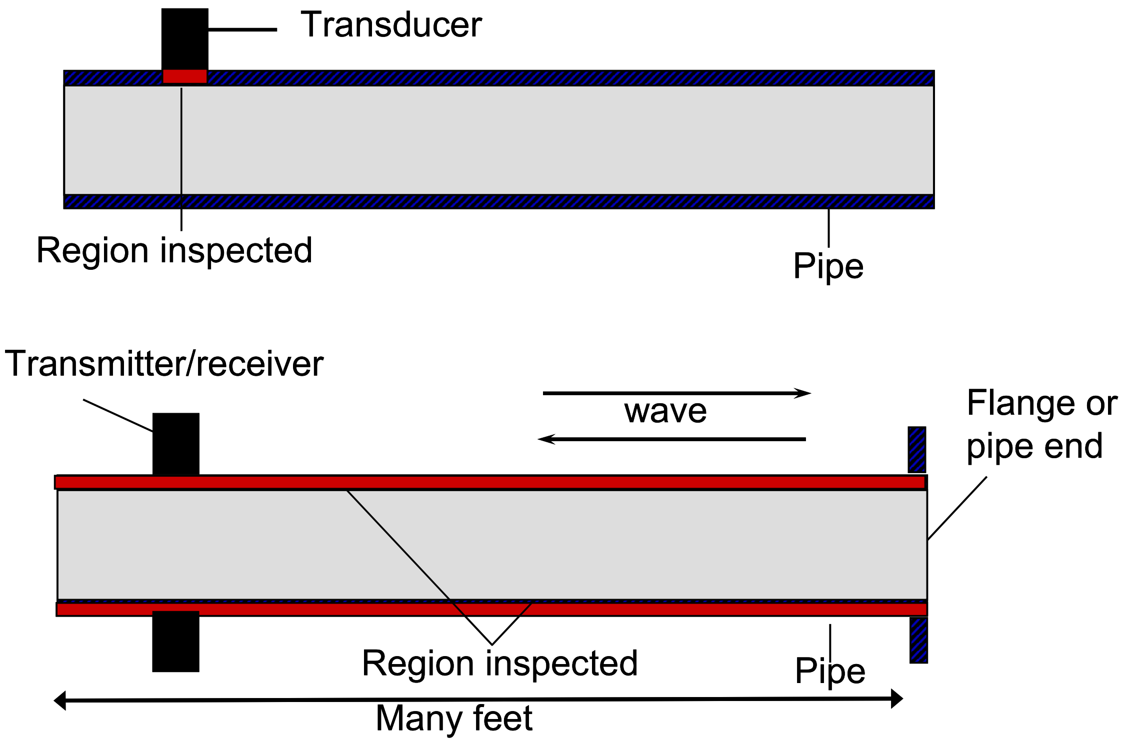
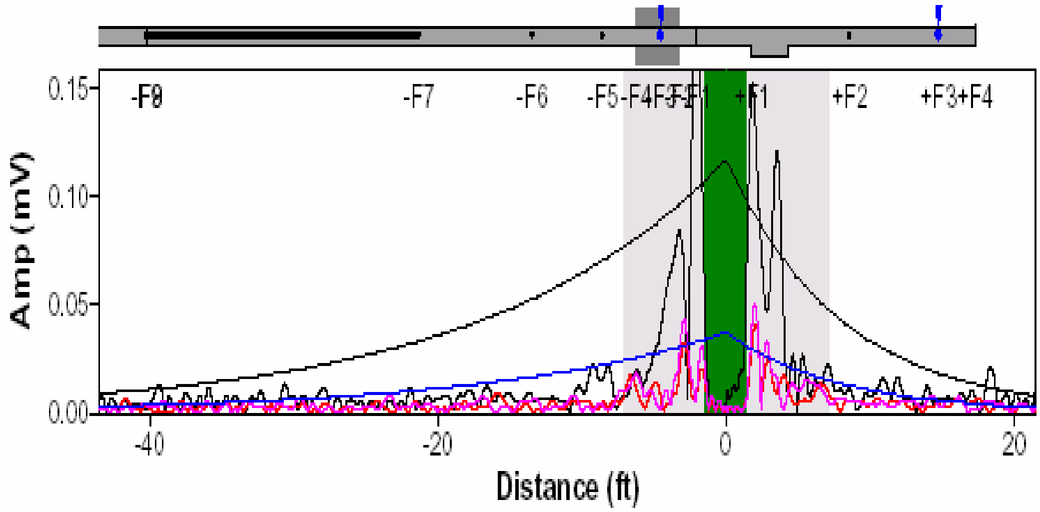


Figure 5. Typical UT (upper) vs. Long Range Guided Wave UT

The G-Scan™ system is a low frequency ultrasonic guided wave technique developed for the rapid survey of pipes to detect both internal and external corrosion. Guided wave ultrasonic inspection uses multiple transducer arrays to direct sound energy in a circumferential mode, which creates torsional guided waves. These torsional waves propagate down the pipe and reflect off features such as welds, supports, or areas of wall loss. Reflections are presented in a pseudo A-scan format on the computer screen in either black (axi-symmetric reflection) or red (non-axi-symmetric reflection). The black line's amplitude is proportional to the total cross sectional area change. The red line's amplitude is inversely proportional to the extent the cross sectional change covers the circumference of the pipe. Interpretation of the inspection results is based on the integration of these two signals' amplitude, symmetry, and the wave shape as well as with the detailed design and installation information. Figures 6 and 7 show typical G-Scan™ data and corresponding pipe features.



Feature	Location	ECL	Class	Notes
+F1	1'9"	-	Y	
+F2	8'7"	13	Minor	70% Circ. Affected Estimated 19% wall loss
+F3	14'9"	12	Medium	50% Circ. Affected Estimated 24% wall loss
+F4	17'3"	-	Flange	
-F1	-2'1"	-	Weld	
-F2	-3'3"	-	Entrance	Concrete Wall starts
-F3	-4'6"	18	Medium	70% Circ. Affected Estimated 25% wall loss
-F4	-6'3"	-	Exit	Concrete Wall ends
-F5	-8'7"	11	Minor	60% Circ. Affected Estimated 18% wall loss

Figure 6. G-Scan Outputs

G-Scan detects changes in effective cross section (ECL) to provide a first order estimate of the amount of metal loss. Circumferential cracks and metal loss due to corrosion or wear that produce an ECL greater than 3% are detectable. In addition, the symmetric nature of each indication provides a measure of the degree of localization of the detected effect. That degree of localization and the ECL can then be used to approximate the depth of localized metal loss. Metal loss from either or both ID and OD can be detected. G-Scan provides an effective method for rapid and complete coverage of piping with limited accessibility, such as buried piping or piping under insulation. Screening inspections using G-Scan provide an indication of where piping is degraded and provide an initial estimate of the degree of degradation. The location of the degradation (i.e., distance from the transducer collar) is shown very precisely. Those features permit piping "hot spots" to be identified and examined in greater detail using other tools as necessary.

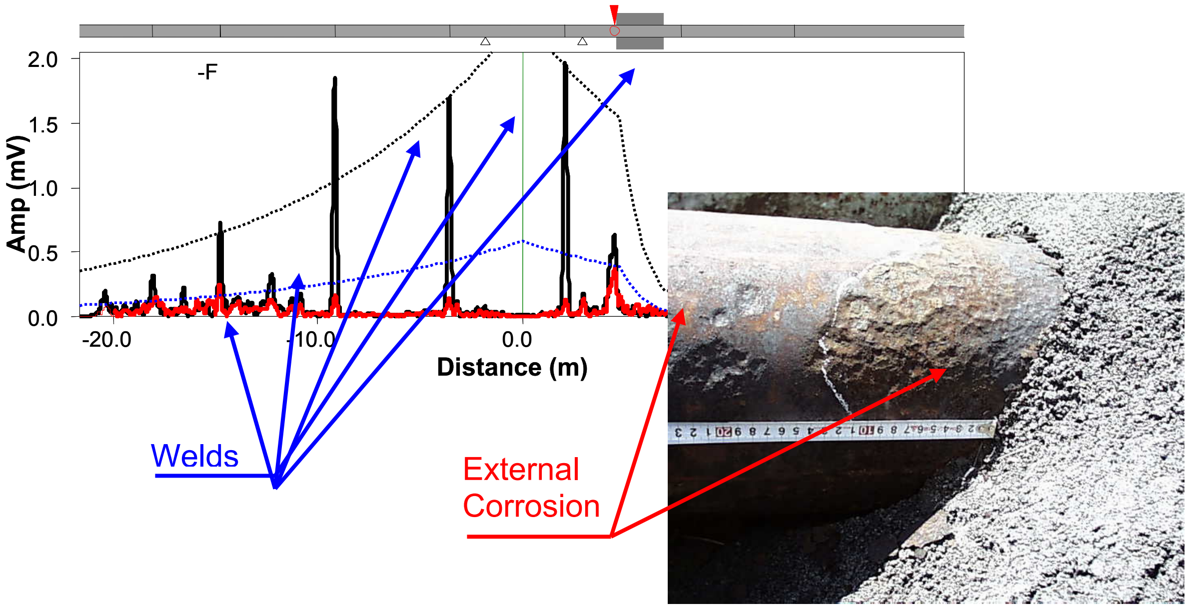


Figure 7: Typical G-Scan™ Data and Corresponding Pipe Features

RESULTS

Figure 8 shows the 54" service water system line that had been identified as the source of the leakage at Dresden. A G-Scan collar was attached to the pipe at an accessible location inside the turbine building to assess the condition of the piping moving downward and toward the suspected location of the leak. Figure 9 provides the results of that single shot. As shown, the shot propagated downward through the building floor, through a mitered elbow and into the horizontally oriented buried pipe. Total length of the shot was approximately 80 feet, including nearly 70 feet of buried pipe. The shot revealed the probable leak location, 41'6" from the collar location, feature +F16 on Figure 9. In addition, several other degraded locations were identified with that one shot. The depth and area of the degraded areas were determined from the G-Scan examination.

The G-Scan inspection located the leak, which was determined from the G-Scan to be a hole approximately ¼ inch in effective diameter. The G-Scan inspection also provided a quantitative assessment of the degree of thinning at the leak location and in other locations along the length of the line as shown in Figures 8 and 9

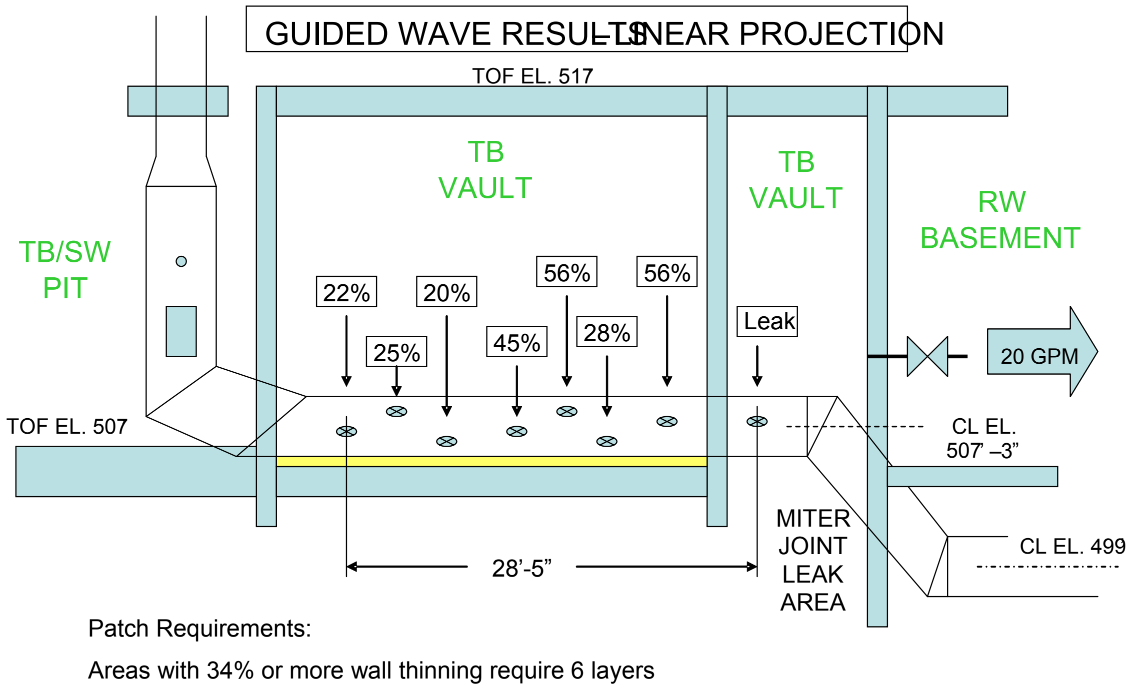


Figure 8. G-Scan Results from Dresden 54" Service Water Pipe

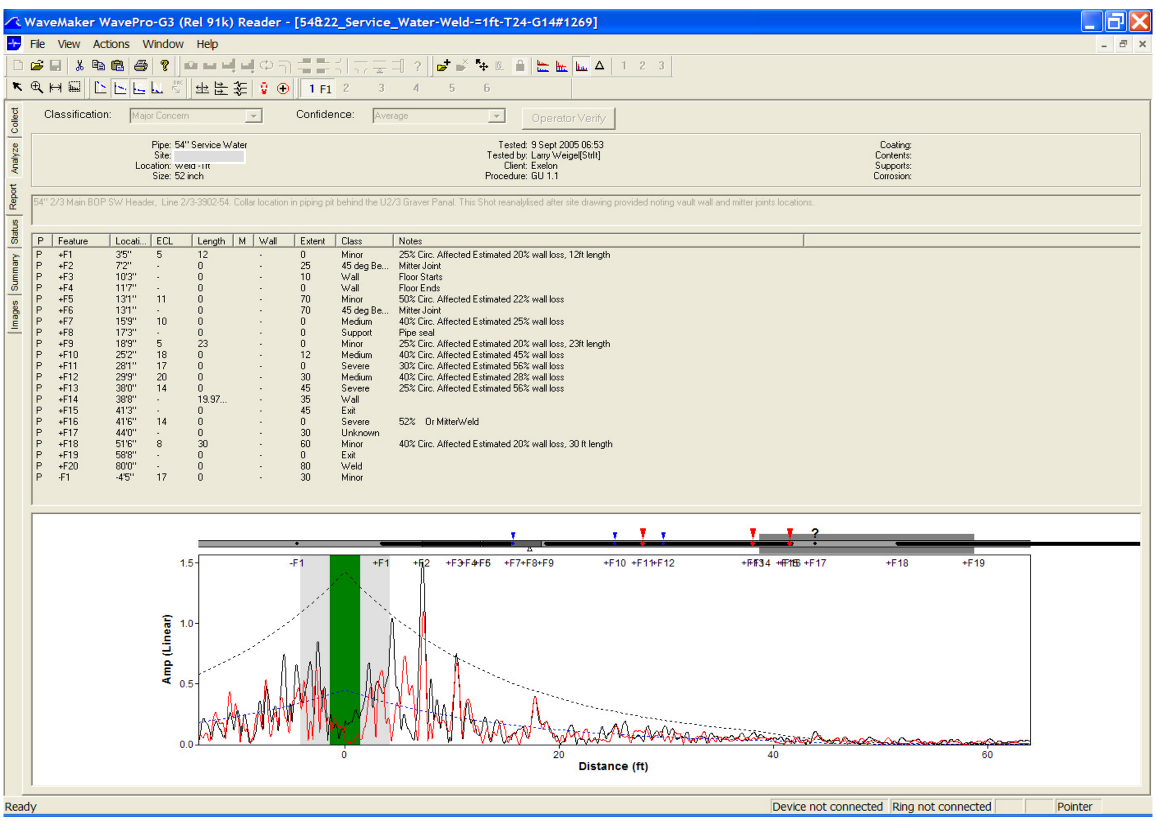


Figure 9. Dresden G-Scan Results

In parallel with the inspection, SI performed an engineering evaluation of the most degraded area (the probable leak site) as well as conducted multiple calculations and cases to define allowable wall thickness requirements for both design and operating pressures. The Code of Construction, B31.1 (for Service Levels A, B, C, & D), and ASME Code Case N-597 (a Section XI Code Case) were used for guidance. The results of those calculations (Figure 10) showed that the structural integrity of the line was not in jeopardy and that a significant margin against rupture existed for all operating conditions. The line can tolerate a very long and deep flaw before rupture.

The inspection results, the engineering evaluations of the degraded areas (the most degraded area and probable leak site as well as other degraded areas in the same length of pipe) permitted the plant to explore options other than an immediate dual unit shutdown that would be required if the line was dewatered for inspections and repair from the interior. The large margins against rupture provided the plant with the confidence to continue to run for an additional six weeks, until one of the units was scheduled for an outage. Avoiding an immediate outage and keeping both units on line, until one of the two units was scheduled for an outage, avoided an unforced two unit outage. At an average 2005 power cost of $0.0461 per kW-hour for the state of Illinois (national average was slightly higher at $0.0573), keeping a 912 MWe plant on line for an additional six weeks had a value of more than $40,000,000.

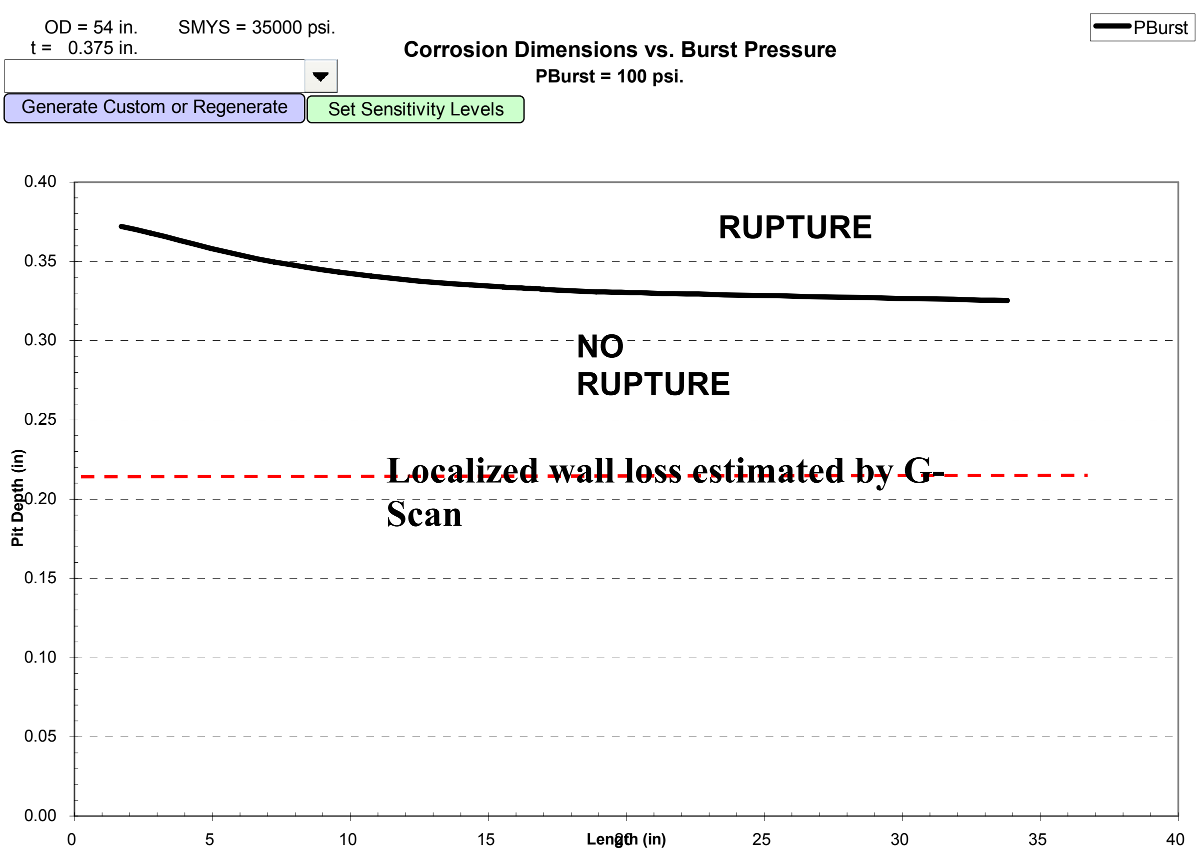


Figure 10. Engineering Evaluation of Thinned Area

When the two units were brought down and the line was dewatered, inspection and repair crews walked to the leak location, at exactly the distance from the G-Scan collars that had been determined from the G-Scan inspection. Figure 10 shows that the interior of the pipe was actually in very good condition, that the leak was the result of a hole approximately ¼ inch in diameter, and that the leak was initiated from the pipe exterior. Other thinned locations as identified by the G-Scan inspection had little or no evidence of degradation from the pipe interior. Prior to the outage, a repair approach, using carbon fiber reinforced epoxy applied from the pipe interior, was designed. The repair included multiple layers of the epoxy patch, with the thickness of the patch determined from the size and thickness determined from the G-Scan inspection.

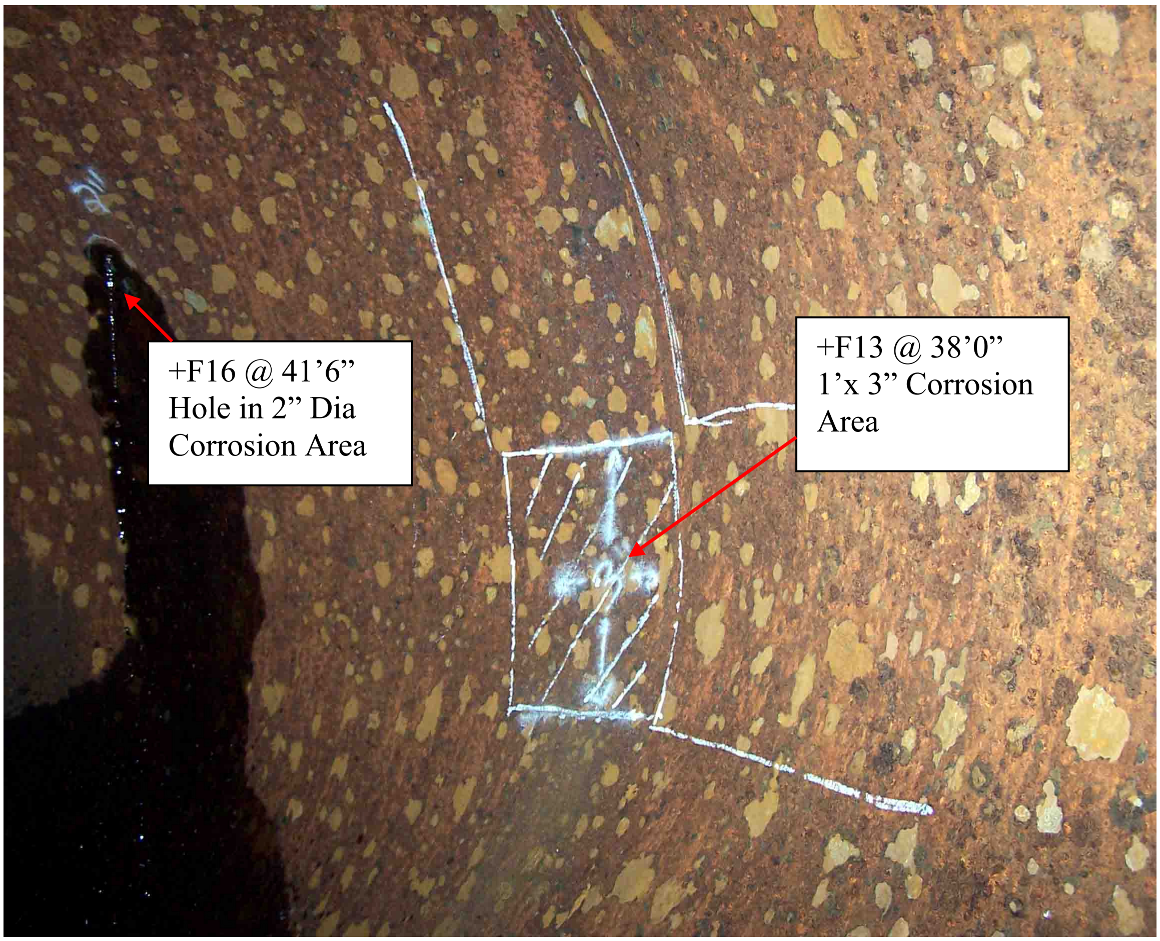


Figure 10. Location of Leak and Other Degraded Area

After dewatering, detailed UT and visual inspection from the pipe ID confirmed the G-Scan results and provided some additional refinements that were useful for more detailed calculations and design of the repair. Access to the pipe wall permitted the wall thickness estimates from G-Scan to be verified using B-Scan from ID. Locations were marked for the carbon fiber repair team.

CONCLUSIONS

G-Scan™ located the leak and provided sufficient information on the location of the leak, and the extent and depth of thinning in the vicinity of the leak to perform an operability evaluation and to design a repair.

The operability evaluation permitted operation of both units to continue until the time of the Unit 2 outage, approximately 6 weeks after the detection of the leak. At that time, both units were brought down and the line dewatered to permit additional inspection and installation of a local repair.

Locations and sizing from the G-Scan inspection were confirmed from other inspections once the pipe was dewatered.

The duration of the two unit outage was minimized and unscheduled downtime was reduced significantly. Avoiding an unplanned dual unit outage produced a very significant savings.

The problem and resolution were shared with the rest of the domestic nuclear industry in Operating Experience Item #75579, later renumbered as 21520.