2019 | VOLUME 45

Structural Integrity Associates, Inc.

NEWS & VIEWS

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LATITUDE™ Delivers

Highlights from the First Field Deployments 28

IMPROVED ASSET MANAGEMENT THROUGH TEST INFORMED ANALYSIS 6

Improve asset management decisions; analyses should be informed by real-world testing

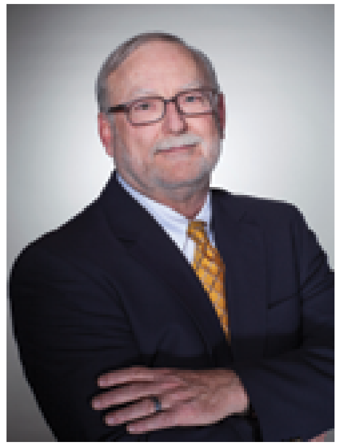
LIFE MANAGEMENT FOR HIGH ENERGY PIPING (HEP) 22

Steps required to implement an HEP / CPS life management program

GAS PIPELINE SAFETY REGULATION UPDATE 32

Comprehensive understanding of proposed pipeline safety regulations.

President's Corner



LANEY BISBEE

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For those of you that have been clients of Structural Integrity (SI) for many years, I'm sure you're more than familiar with our tagline. I'm not going to repeat it here because it is now officially our former tagline. For over three decades it worked for us, highlighting our expertise around structural and mechanical failures. But, as you likely know, we've expanded the breadth of our capabilities and services over the years to the point that our support for clients covers far more than simply preventing and controlling failures (structural, mechanical or otherwise). After all, our services around nuclear fuel design or chemistry or seismic certifications or medical devices don't have much to do with structural failures. Therefore, we needed a new tagline to go along with our total brand refresh.

To ensure that our new tagline would not only work for us today but also far into the future, it had to capture the commonalities among all our current business lines and strategic areas for expansion. We also wanted the tagline to capture our distinctive position and culture in the consulting market. With those goals in mind, it became clear that three hallmarks of SI define us.

Powered by Talent & Technology

Undoubtedly, the heart of everything we do is our people. The collective expertise, years of experience and industry leadership – our **talent** – enables our clients to trust that we will deliver in solving their most difficult problems and challenges. This is true for every market we serve and every SI role including our consultants, engineers and NDE professionals. And, while I don't often get to talk about them, our talent extends to our corporate services departments as well – Finance, Accounting, Human Resources, IT, Quality, Safety, Risk Management, Marketing, etc. – all the critical business infrastructure capabilities that allow us to focus on all our client's needs, not just their technical problems.

The other hallmark of SI is innovation, which usually manifests itself through **technology**. We pride ourselves on our record of industry leading innovations, with new designs of NDE systems, advanced software tools and advanced analytical methodologies. Many companies only use off-the-shelf **technology** they can buy, but I'm proud of SI's desire and ability to develop new **technology** and push boundaries of what we all thought was possible. Just as with our **talent**, our development and application of **technology** runs throughout our business. In fact, we recently kicked off our 2019 budgeting process and I realized that we have several technological innovations to roll out in the very near future in every market we serve. You'll read about some of them in these pages and will certainly learn about more of them in the future – some of them solve new problems while others lead to new ways of solving old problems.

Finally, **powered by** describes how we operate as an independent, employee owned business – we move or travel with great speed or force. While other companies simply exist, and can exhibit a static culture, we intend to continue to be dynamic in action, responding with urgency to the shifts in the markets we serve and associated regulatory environments to maintain our leadership position.

Expect to see and hear more about our new tagline and rebranding. We think it represents SI well with just a few simple, but powerful, words. One place you're sure to see it is on our new website. Be sure to visit it to learn more about how SI is "Powered by Talent & Technology".

Powered by Talent & Technology

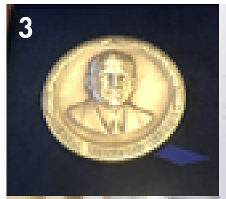
Dan Peters: 2018 Recipient of the J. Hall Taylor Medal

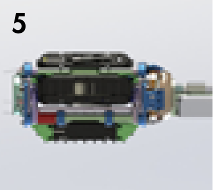
The J. Hall Taylor Medal is presented for distinguished service or eminent achievement in the field of codes and standards pertaining to the broad fields of piping and pressure vessels which are sponsored or undertaken by ASME.

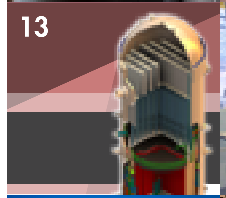
Mr. Peters is recognized for the outstanding contributions to the development and promotion of ASME codes and standards for pressure equipment; and for efforts to enhance public safety and component reliability through dedicated service on the Society's pressure vessel and piping committees.

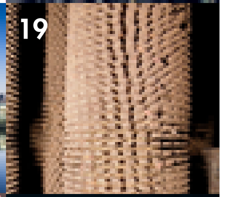
Mr. Peters' activities over the last twenty years have focused on risk based inspection planning for management of key assets and the design and analysis of high-pressure equipment, including the application of fracture mechanics for evaluation of the life of the equipment. Mr. Peters became active in the American Society of Mechanical Engineers both in the area of Codes and Standards and technology development through the Pressure Vessel and Piping Division. He has championed many initiatives in bringing together technology development from the ASME TEC Sector with Codes and Standards development. He has held several offices and positions within ASME Codes and Standards, including Chairman of several subgroups, members of both the Committee on Pressure Vessels (VIII) and Post Construction Committee (PCC), Member of the Board on Pressure Technology Codes and Standards and the ASME Council on Standards and Certification. Mr. Peters has authored or coauthored papers in this area with subject matter including cycle life of pressure vessels and high pressure components, asset management of equipment, and stress concentration factors at cross-bores of cylinders. Mr. Peters has been with Structural Integrity Associates for over 13 years and currently leads the Critical Structures and Facilities group on Pressure Vessels and Piping.

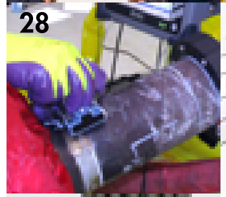
Dan Peters received the J. Hall Taylor Medal at the IMECE, International Mechanical Engineering Congress & Exposition, President's Luncheon on Monday, November 12th 2018 in Pittsburgh, Pennsylvania.

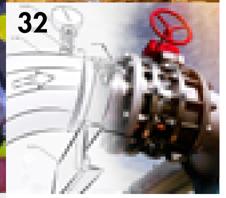


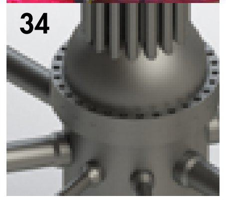












In this Issue

New Partnership for Robotic ILI Sensor

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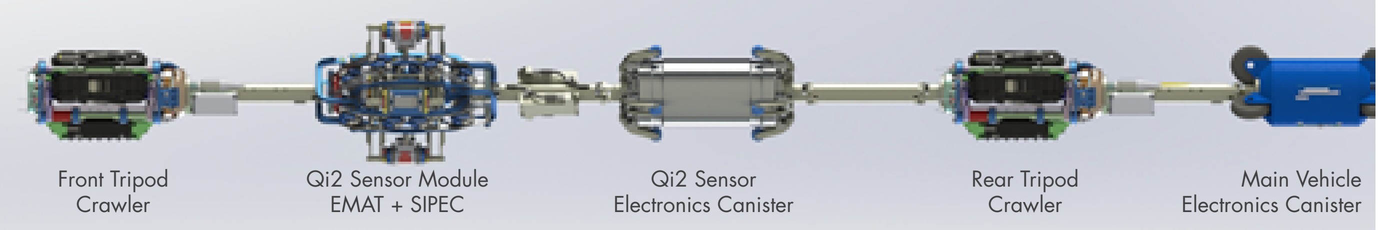

Robotic NDT Internal Pipeline Tool Development

Structural Integrity (SI) and Quest Integrated (Qi2) have recently executed an agreement to integrate and deploy advanced sensor technology using Robotic In-Line Inspection (R-ILI) devices. Qi2 is a leader in the development of intellectual property and technology solutions with a focus on advanced non-contact measurement systems and sensor solutions. Qi2's experience includes technology applications in laser profilometry, electromagnetic acoustic transducers (EMAT), piezo-based ultrasonics, microelectronics, computational measurement of complex geometries, and novel materials development. Through the integration of SI's patented SIPEC™ dynamic Pulsed Eddy Current (PEC) technology and Qi2's EMAT sensor technology with a wide-range of state-of-the-art robotic platforms, the team will deliver one of the most comprehensive and capable suites of remote inspections solutions available in the industry. For our clients, this means inspection of previously inaccessible areas, less cleaning prior to inspections, improved inspection coverage, and shorter inspection evolutions.

Many pipelines, segments, and components are not conducive to conventional In-Line Inspection (ILI) or current R-ILI solutions and direct examination of the component using traditional NDE methodologies is prohibitive. For example, tight radius bends, short runs, dimensional changes, low-flow pipelines, single-point access, unbarred tees and internally lined piping can pose a challenge for conventional tools and/or may not be cost effective. The combination of a dynamic PEC metal loss sensor, together with a delivery solution that can navigate "inaccessible" locations, can increase safety by allowing the inspection of a new class of components previously un-inspectable or deemed "extremely costly" to inspect. This methodology can be used in hazardous liquid, natural gas, petrochemical and the water industries and can be applied to any ferrous metal that is susceptible to corrosion degradation.

The SIPEC technology is useful for inspecting components for wall loss through internal liners or in situations where relatively large sensor liftoff may be necessary, such as crude and refined products pipeline that may not be thoroughly cleaned. The dynamic SIPEC technology has several advantages over other existing PEC technologies including improved spatial resolution; improved signal-to-noise ratio; the ability to distinguish between internal and external metal loss; and most importantly, the ability to rapidly acquire data while in motion (dynamic data acquisition).

SI is proud to be teaming with Qi2 to bring this new technology to our clients. We will be releasing more detailed information and specifications about the technology in the near future and look forward to the first field applications in 2019.

Improved Asset Management Through Test Informed Analysis

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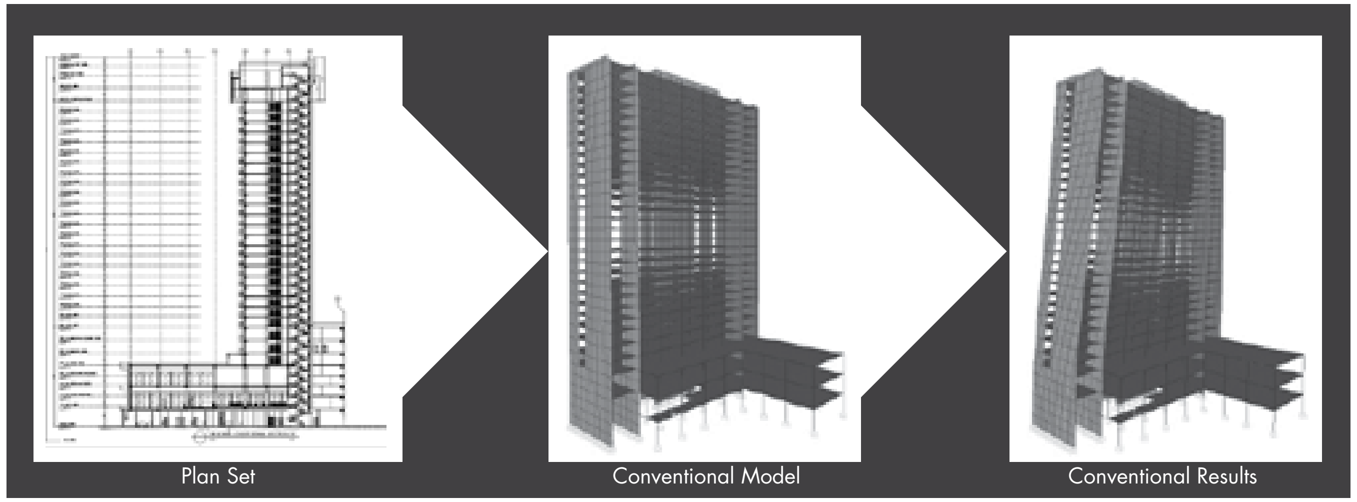
Introduction

Structures may experience unforeseen operating environments or site-specific hazards leading to changes in the structure's performance, safety, and longevity. These changes often prompt asset owners to undertake analysis efforts to ensure satisfactory structural performance for the updated conditions. However, conventional analyses that fail to capture the true behavior of a structure can lead to inaccurate analysis results, causing owners to make less than ideal asset management decisions. Structural Integrity (SI) is uniquely positioned to pair our dynamic characterization and advanced structural analysis capabilities to generate a better structural model. SI vibration experts use impact testing, forced vibration, or ambient excitation sources, along with proprietary signal processing software, to non-destructively characterize the dynamic behavior of structural systems. This characterization is used to inform advanced structural analyses by SI analysis experts to provide more accurate results related to operational improvements, damage location, and retrofits.

Overview

A conventional analysis approach is to use available plan sets and construction documents to generate a structural model of an asset. This model is then subjected to various loads or operating environments to predict the current structure's behavior. This approach is summarized in Figure 1.

Unfortunately, this approach gives no assurances that the developed analysis model appropriately represents the actual structure. Variances in material properties, mass distribution, time-dependent properties, accumulated degradation, and changes not represented in the as-built plan sets may lead to an analysis model that fails to identify deficiencies in the real-world structure. This may lead to less than ideal asset management decisions as owners may pursue unnecessary repairs or be unaware of current deficiencies.



Plan Set

Conventional Model

Conventional Results

FIGURE 1. Typical Analysis Procedure

To improve asset management decisions, analyses should be informed by real-world testing. Testing can be either destructive or non-destructive, with information collected from either static or dynamic tests. To minimize costs and invasiveness, SI uses non-destructive dynamic testing to identify key characteristics of a structure and uses the test results to improve the structural analysis models. For instance, accelerometers can record the response of a structure to ambient excitations and provide insights to the structure's natural frequencies and mode shapes. Knowing the key characteristics about the real-world structure allows SI to update the "conventional" analysis model to ensure that the "benchmarked" analysis model accurately represents the real-world structure, allowing for improved asset management decisions. This approach is summarized in Figure 2.

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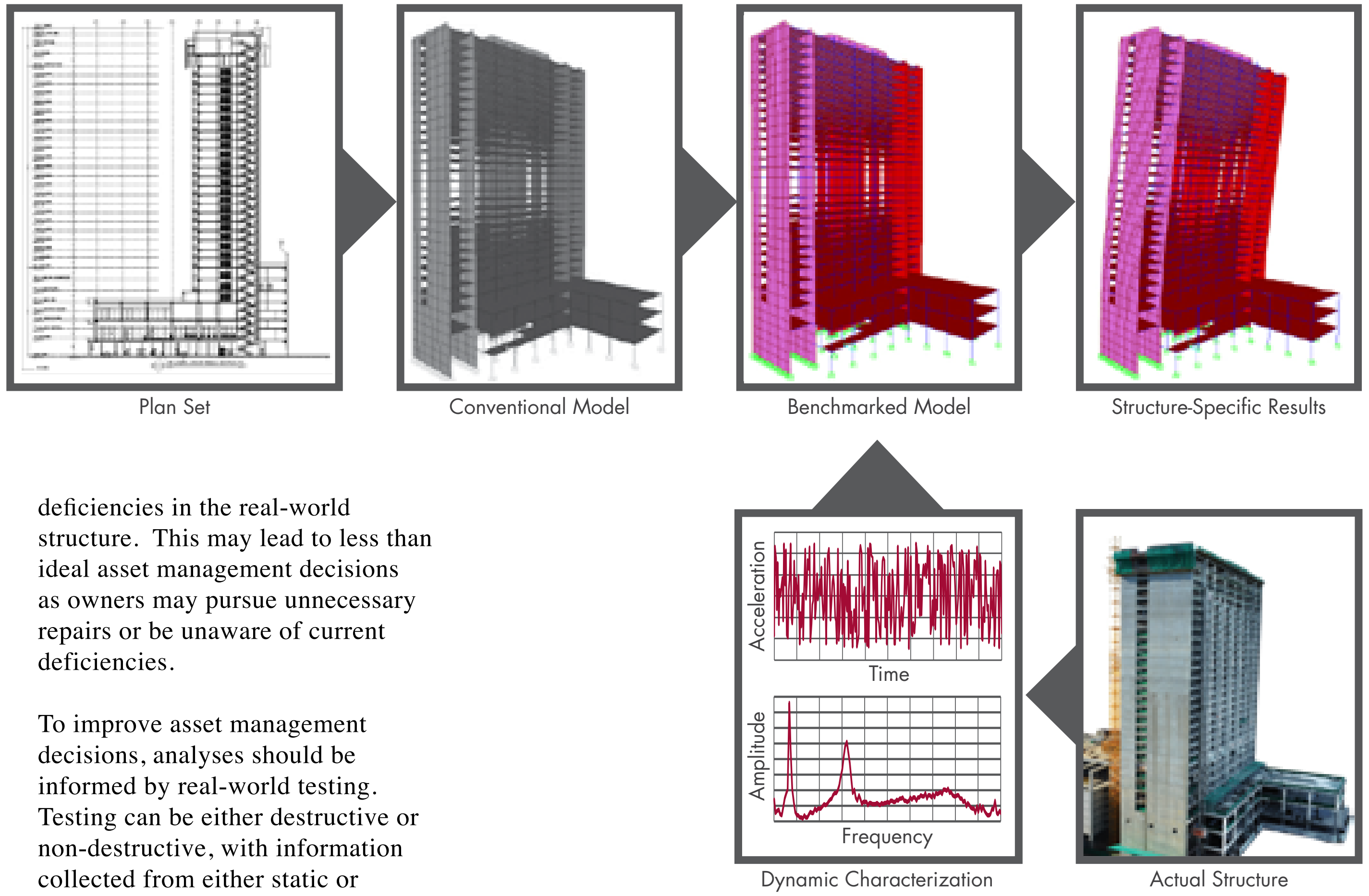


Plan Set

Conventional Model

Benchmarked Model

Structure-Specific Results

Dynamic Characterization

Actual Structure

FIGURE 2. Enhanced Analysis Procedure

Discussion

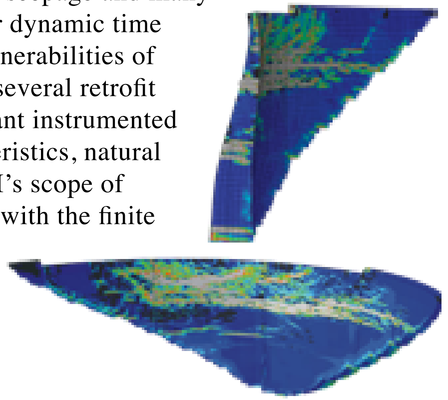
Analysis models based on plan sets, construction documents or other limited information may lead to models that do not represent the true in-situ state of a structure. To improve asset management decisions, analyses should be informed by real-world testing. Structural Integrity (SI) has the capabilities and experience to both dynamically characterize a structural asset and build a test-informed analysis model. Test-informed analysis models lead to more confidence in the analysis results and subsequent asset management decisions. With both characterization and analysis competencies in-house, SI offers a one-stop shop to help owners better manage their high-value assets.

REPRESENTATIVE PROJECTS

The following SI projects have used dynamic characterization to lower client costs, improve analysis results, and/or aid owners in asset management decisions.

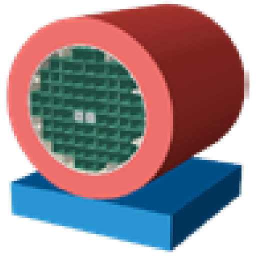
STRUCTURE: Hydroelectric Dam
OWNER: Water and Power Utility
EXCITATION: Ambient
ANALYSIS TYPE: Nonlinear Time History Analysis
OBJECTIVE: Seismic Vulnerability and Retrofit Assessment

The owner of an unreinforced concrete arch dam was required to address design and safety issues due to increased seismic hazard classification and probable maximum flood levels prior to relicensing by FERC. Built in the 1920s, this dam has significant concrete degradation due to seepage and many freeze thaw cycles. SI performed nonlinear dynamic time history analyses evaluating the as-built vulnerabilities of the structure and assessing the efficacy of several retrofit modifications. Previously, another consultant instrumented the dam to determine the dynamic characteristics, natural frequencies and mode shapes. As part of SI's scope of work eigenmode analyses were performed with the finite element model. The calculated natural frequencies were within a percent of the on-site measured frequencies. This close agreement gave confidence in SI's nonlinear analysis methodology to the owner and FERC regulators.



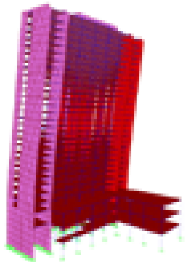
STRUCTURE: Nuclear Fuel Packages on a Vehicular Trailer
OWNER: Nuclear Fuel Manufacturer
EXCITATION: Highway Transportation Vibration
ANALYSIS TYPE: Spectral Analysis and Operational Deflected Shapes
OBJECTIVE: Vibration Study

A fuel manufacturer ships nuclear fuel across the country via trailer transport. SI was contracted to develop a test procedure and a mobile data acquisition system to measure the vibration acceleration experienced by the trailer and fuel packages during shipments across the United States. The system measured accelerations over the course of the multi-day shipment. SI analyzed the data to better characterize the vibration acceleration amplitudes as well as frequency content of the trailer-package-fuel assembly system as vibration is transmitted from the road through the trailer suspension, packages, and into the fuel assemblies. The improved understanding of the vibration signature for the transport system assisted the manufacturer in making decisions on how to best mitigate vibration levels during future transportation.



STRUCTURE: High-Rise Concrete Hotel
OWNER: Private Owner
EXCITATION: Ambient (Wind) Vibration
ANALYSIS TYPE: Nonlinear Time History & Nonlinear Pushover
OBJECTIVE: Support New Design

Tobolski Watkins Engineering (TWE), acquired by SI in 2017, provided structural and seismic consulting related to the nonlinear analysis of a 30-story hotel to determine acceptable performance of the building during large earthquakes and tropical storms. TWE developed a 3D finite element model of the building to perform nonlinear time history analyses, modal analyses, and nonlinear pushover analyses. Additional work included in-situ testing of the main tower to determine the damped natural frequencies of vibration of the bare frame structure, prior to the construction of building cladding and nonstructural components. The purpose of the testing was to provide input for calibrating the finite element model of the building and for use as input to extreme wind load calculations.

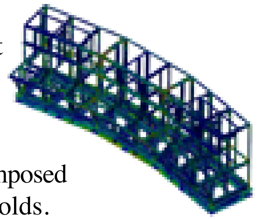


STRUCTURE: Induced Draft Fan
OWNER: Power Utility
EXCITATION: Impact Hammer, Externally Driven & Operationally Driven
ANALYSIS TYPE: Foundation Investigation
OBJECTIVE: Root Cause Analysis

A power utility noted excessive operational vibrations in an induced draft fan forcing the fan to be pulled from service, lowering the plant's power output and daily revenue. SI was brought in to investigate the fan's concrete foundation as a potential cause. SI performed a variety of in-situ dynamic tests to characterize the system including impact hammer tests of the stationary fan blades and concrete foundation, a frequency sweep of the system using a linear mass shaker and recorded 96 channels of data at various points in the system during quasi-operational runs. Interpretation of the recorded data led to a shift in focus from the foundation to the fan's bearing. Disassembly of the fan bearing revealed several issues that were quickly resolved. Quasi-operational runs after reassembly showed a marked reduction in the operational vibrations, leading the fan to be put back into service.

STRUCTURE: Remote Shutdown Console
OWNER: Nuclear Utility
EXCITATION: Shake Table
ANALYSIS TYPE: Nonlinear Time History Analysis
OBJECTIVE: Seismic and Shock Base Isolation

Due to an increase in the required seismic ground motion and the inclusion of an aircraft impact load case, a nuclear utility sought to base isolate a remote shutdown console. Since the console needed to remain operational after the dynamic load cases, a fragility analysis was also needed. SI developed a finite element model of the console and used shake table test data, provided by the equipment manufacturer, to validate the modeling approach. SI then performed nonlinear time history analyses to investigate the feasibility of a shock mount system for the console. The in-console response was used to determine the fragility demands imposed on the console, which were compared to client-defined thresholds.



The Importance of HRSG HP Evaporator Tube Internal Deposit Evaluation

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Evaluation of High Pressure (HP) Evaporator Tube Deposits is important for several reasons:

- Determining if flow-accelerated corrosion (FAC) might be occurring in the lower pressure circuits.
- Regular evaluations can provide information on the internal deposit deposition rate, which is information necessary to help prevent under-deposit corrosion damage mechanisms.
- Provides information necessary to develop an optimized cycle chemistry for HRSGs.
- Can help determine if the HRSG needs to be chemically cleaned.

The leading heat recovery steam generator (HRSG) tube failure mechanisms are FAC, thermal and corrosion fatigue, and under-deposit corrosion (UDC) and pitting. The corrosion products released by the FAC mechanism are transported from the affected area (typically the feedwater or lower pressure systems) and can eventually reach the HP evaporator tubing, so understanding the deposition in the HP evaporator is an important step in determining if FAC might be occurring. Deposition on the inside of HP evaporator tubing is also a precursor to any of the under-deposit corrosion HRSG tube failure mechanisms. Controlling UDC damage requires, among other steps, removing HP evaporator tube samples on a regular basis to determine the deposition rate. Developing an optimized cycle chemistry for HRSGs is intimately related to understanding the formation of deposits in HP evaporators. And lastly, an evaluation of the internal deposits in HP evaporator tubes can help determine if the HRSG needs to be chemically cleaned.

Structural Integrity (SI) has been conducting internal deposit evaluations on HP evaporator tubes for over ten years and generally follows the IAPWS guidance on performing these analyses (International Association for the Properties of Water and Steam, IAPWS TGD7-16, Technical Guidance Document: HRSG High Pressure Evaporator Sampling for Internal Deposit Identification and Determining the Need to Chemical Clean, www.iapws.org). A standard evaluation consists of the following steps:

- Measuring the deposit weight density to determine the overall loading (indigenous oxide + deposits/reaction products).
- Optical metallographic examination and documentation of cross-sections through the tube, indigenous magnetite, and deposits.
- Measuring the total thickness of the indigenous magnetite and deposit layers from the metallographic samples.
- Scanning electron microscopy (SEM) and elemental mapping by energy-dispersive x-ray spectroscopy (EDS) of cross-sectioned oxide/deposit layers to determine the distribution of elements and whether any reaction products are present within the deposit.
- X-ray Diffraction (XRD) is used to identify the compounds within the deposits, if necessary.

HP Evaporator tube samples should be removed from locations where the deposit buildup is expected to be heaviest. For horizontal gas path HRSGs with vertical tubes, the lead tube (closest to the gas turbine) towards the top of the circuit near the outlet header is generally a good location. For vertical gas path HRSGs with horizontal tubes, the best sampling location may not be as obvious. The first and last tube in the bundle should cover differences in deposition. For either configuration, tubes on the extremities of the bundles where gases can bypass along the duct, or near the center of the HP evaporator if there is a gap between multiple modules, are locations that can have heavier deposits.

Case Studies

The images in Figure 1 show the internal deposit loading coupons from an HP evaporator tube with a high deposit loading value. The deposits were not ruggedly red and were relatively thick. The deposit loading on the hot side (upper coupon) was 49.4 g/ft^2. No significant pitting or corrosion was observed after cleaning.

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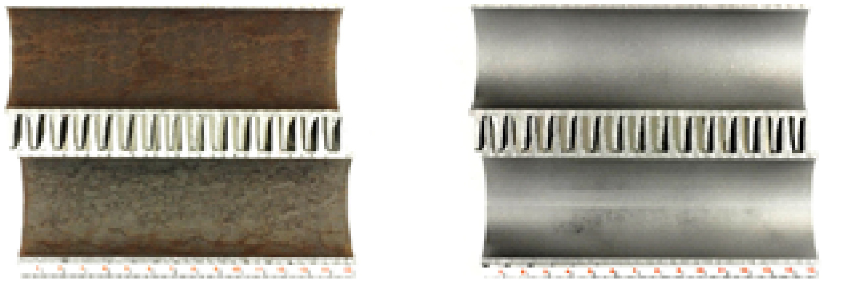


FIGURE 1. Deposit loading coupons before and after cleaning from tube with heavy deposits.

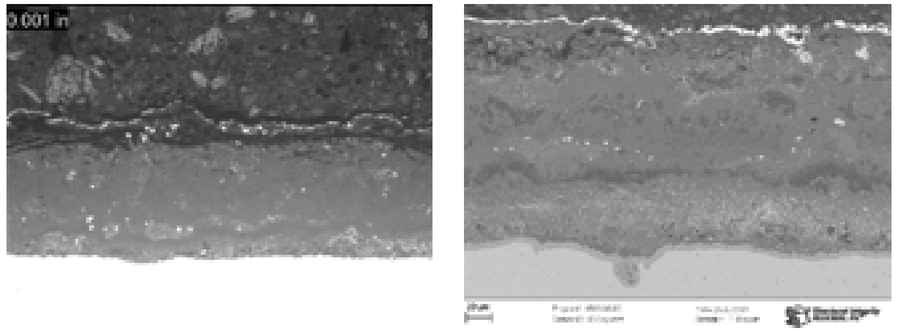


FIGURE 2. Optical metallographic (left) and SEM (right) images through the oxide/deposit layer on the hot side of the tube. The ID surface is facing up in these images. The bright layer along the top of the deposits is from gold coating, which is part of sample preparation.

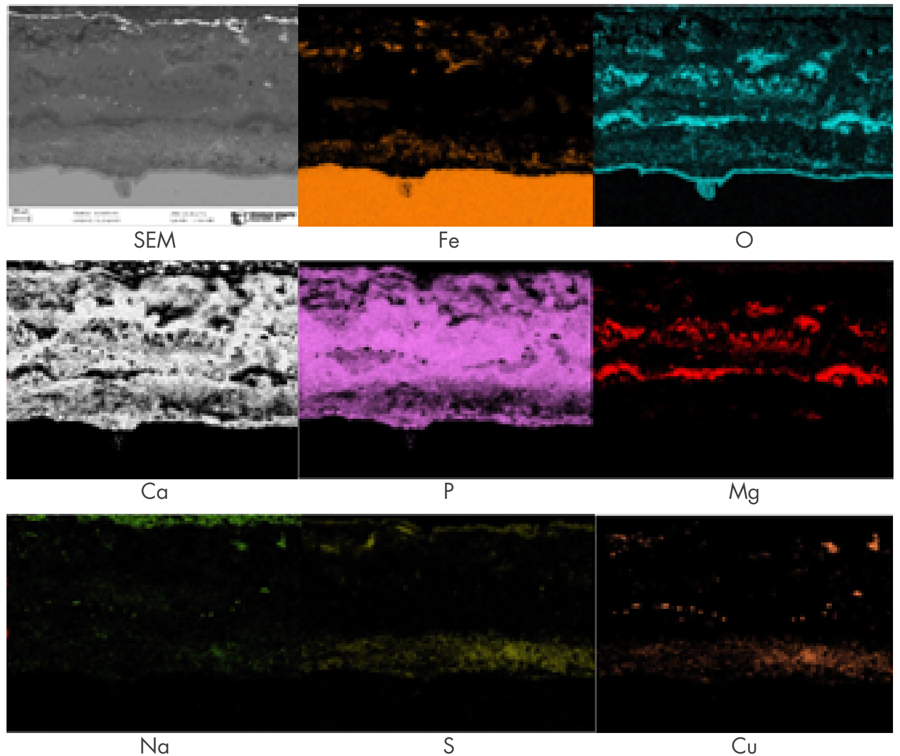


FIGURE 3. EDS elemental maps of deposit layers.

The hot side of the tube was cross-sectioned; optical metallographic and SEM images of the cross-sectioned oxide/deposit layer are shown in Figure 2. The oxide/deposit thickness is 160 microns.

The EDS elemental maps from the oxide/deposit layer are shown in Figure 3. The thin indigenous oxide layer is clearly visible along the tube metal surface. The deposits contain significant amounts of calcium, phosphorus, and magnesium, moderate amounts of sulfur and copper, and trace amounts of sodium.

While no evidence of UDC was observed in this tube, the internal deposit evaluation indicated that UDC would be a concern should contaminant ingress occur. This tube is in the region of the IAPWS Deposit Map for HRSG HP Evaporator tubes that indicates chemical cleaning is necessary.

In another example, Figure 4 shows the internal deposit loading coupons from an HP evaporator tube with a low deposit loading value. The deposits were ruggedly red. The deposit loading on the hot side (upper coupon) was 4.7 g/ft^2. No significant pitting or corrosion was observed after cleaning.

The hot side of the tube was cross-sectioned; optical metallographic and SEM images of the cross-sectioned oxide/deposit layer are shown in Figure 5. The oxide/deposit thickness is approximately 10 microns.

The EDS elemental maps from the oxide/deposit layer are shown in Figure 6, which show that some level of corrosion product concentration is occurring within the deposits and that the tubes should continue to be monitored. However, these tubes do not currently need chemical cleaning.

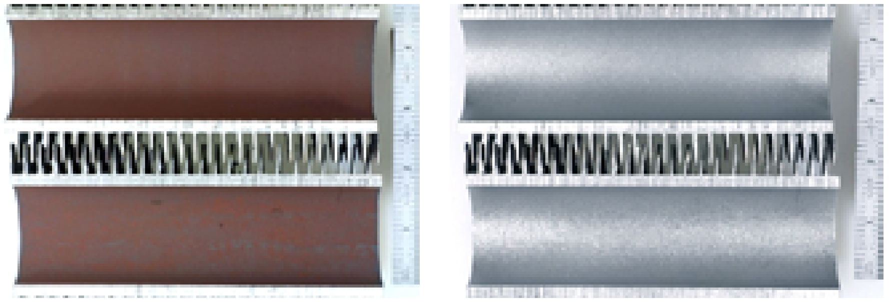


FIGURE 4. Deposit loading coupons before and after cleaning from tube with light deposits.

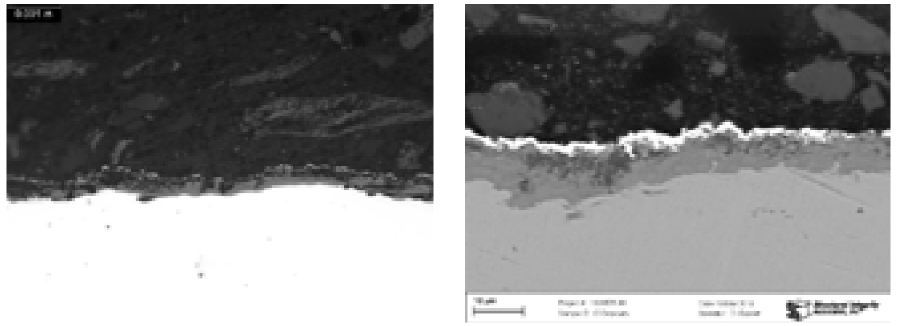


FIGURE 5. Optical metallographic (left) and SEM (right) images through the oxide/deposit layer on the hot side of the tube. The ID surface is facing up in these images. The bright layer along the top of the deposits is from gold coating, which is part of sample preparation.

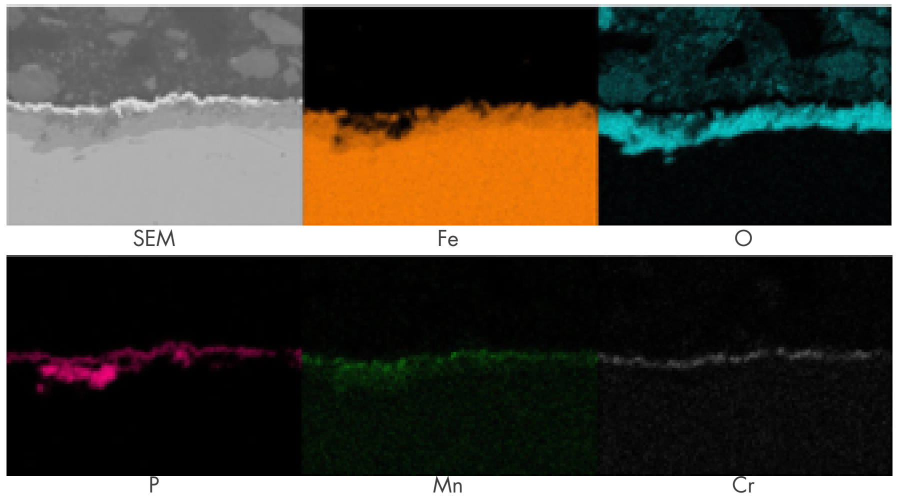
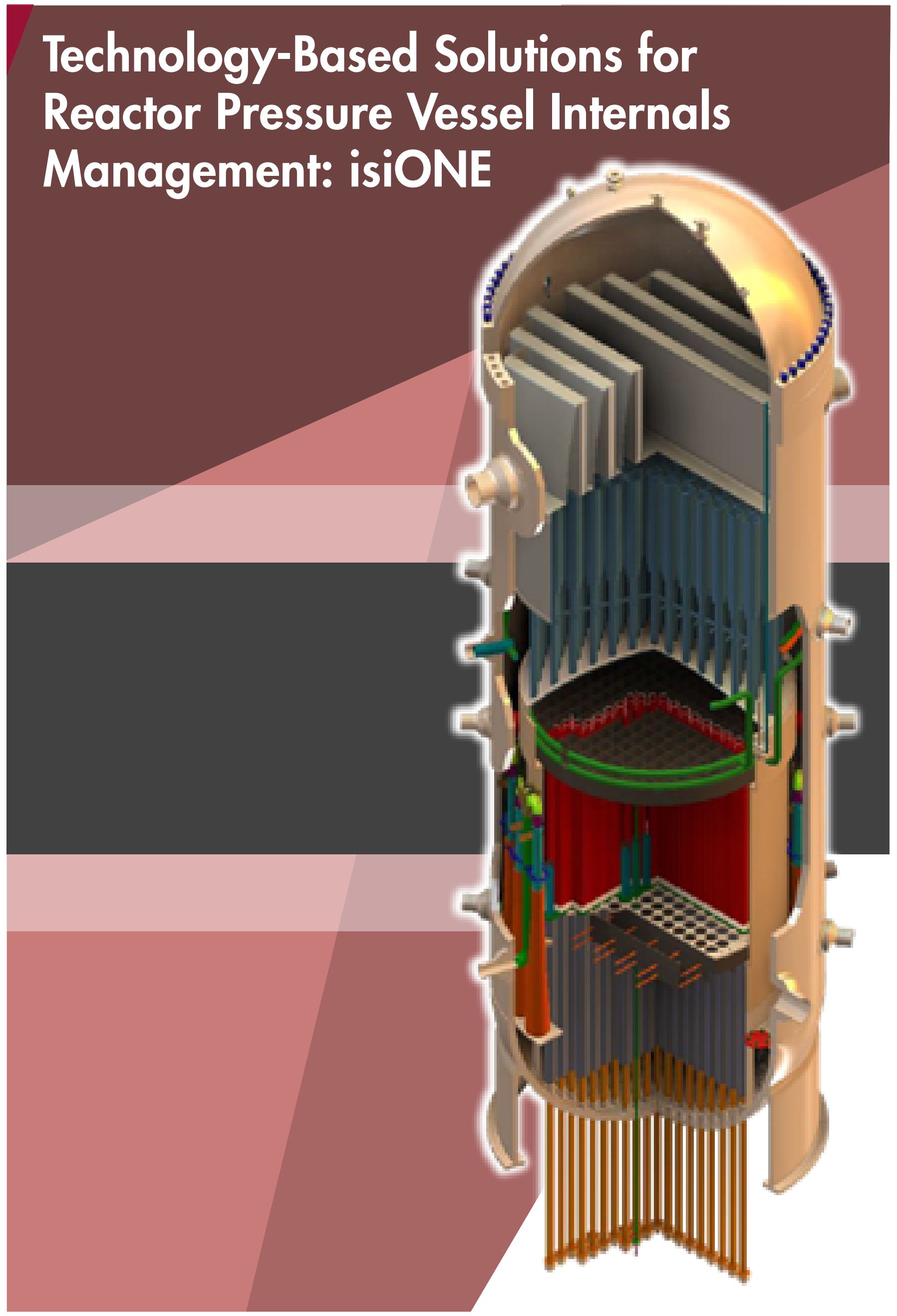


FIGURE 6. EDS elemental maps of deposit layers.

Structural Integrity Signs License Agreement with Innomerics



Technology-Based Solutions for Reactor Pressure Vessel Internals Management: isiONE

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Recently, Structural Integrity (SI) signed a license agreement with Innomerics to bring **isiONE** to the domestic US boiling water reactor market. It has already been deployed at several nuclear power plants in Europe. **isiONE** is a software-based solution specifically designed to manage reactor pressure vessel (RPV) internals. **isiONE** incorporates all relevant documents, regulation requirements, technical specifications, analyses, and inspection and repair history into a single tool with a powerful graphical interface. It can reduce time preparing and planning for RPV internals exams and ensure the inspection program is compliant with EPRI BWRVIP requirements. It also serves as a single repository for all knowledge of the RPV internals program at a utility to allow for easier knowledge transfer at a plant. For more information on **isiONE** or to discuss a demonstration of the software, please contact Matthew Walter.

Proving Performance

What Distinguishes an ISO-Compliant Product Certification Agency?

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Whether it's fair-trade coffee, sustainably harvested lumber, energy efficient appliances, or other certified products, consumers and companies look for products that have high standards of origin, production, and performance. Structural Integrity Associates' *TRU Compliance* mark is no different. Our mark shows buyers a product has undergone rigorous assessment for seismic, wind, and blast performance to nationally recognized standards.

Examples of Certification Marks of Conformity

However, not all agencies conform to the internationally recognized set of standards that govern a product certification agency, allowing it to be impartial, objective, and accountable to the public. The standard ISO/IEC 17065 Conformity assessment -- *Requirements for bodies certifying products, processes and services* spells out requirements that make agencies like TRU Compliance accountable to its clients and to the public. The requirements in TRU Compliance's Certification Manual are broad, but they generally fall into the three categories below.

Structural Requirements

The management structure of TRU Compliance is that it is a separate legal entity operating separately from the consulting arms of Structural Integrity, and accountable to different standards. An annual management review meeting occurs highlighting potential areas for improvement in quality and impartiality. An impartiality committee consisting of experts external to TRU Compliance convenes annually as well and reviews the steps TRU has taken to protect the objectivity of their certifications. This committee has the power to escalate issues to the SI's Quality Assurance department, accrediting organizations, and to halt certification activities until their concerns are addressed.

Process Requirements

Product assessment is carried out to the *TRU Compliance Certification Standard for Seismic, Wind, and Physical Security Performance*, which references national standards from ASCE, ICC-ES, IEEE, ASTM, and others. This standard is available upon request by emailing info@trucompliance.com. The assessment is not offered in conjunction with any consulting activity and TRU Compliance certification engineers are precluded from working on assessments of products for which they provided design advice for a period of two years.

The evidence documenting a product performance is submitted to an expert member of the TRU Certification Decision Maker (CDM) roster who has not participated in the certification activities up to that point. The CDM reviews all pertinent information and makes the final decision on whether the certification can be granted.

Air Conditioning Product Undergoing Shake Table Testing

After a product is granted a certification, the manufacturer submits their production process to periodic surveillance to make sure the products for market are well represented by the products submitted for testing or assessment. TRU staff will review records and make factory or point-of-sale inspections to confirm products can still be marked as TRU Compliance certified.

Public Accountability

TRU Compliance maintains public records of products it certifies on its Seismic Certification Database at TRUCompliance.com. Visitors to the site can search and sort products rated for seismic certification, filtering for product category, seismic level, and building code. Manufacturers who label their products with a TRU certification mark are communicating to discerning buyers that their product has been subjected to industry standard by testing, analysis, or combinations thereof. The mark of conformity allows any user to search for the active listing to verify the product indeed has an active certification.

TRU Compliance is further accountable to the public with its system for public comment and complaints, which are overseen by Structural Integrity's Quality Assurance team (reachable at 877-4SI-POWER). This process allows anyone to file a grievance if they believe a certified product is not in conformance and for the management of TRU Compliance to be held accountable to SI's Quality Assurance department.

With the certification program going active July 2018 and external accreditation expected in early 2019, the TRU Compliance certification has never been a more robust program for seismic, wind, and blast compliance of products. Learn more about the process at TRUCompliance.com.

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Metallurgical Lab:

Case Study – Thermowell Failure Analysis

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FIGURE 1. The fractured thermowell sections shown in the as-received condition. The mating fracture surfaces are facing down on each section.

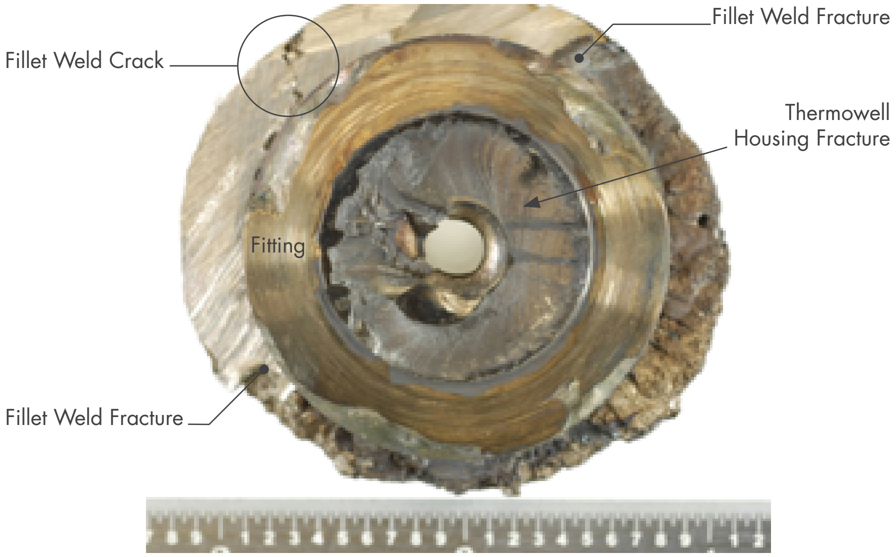

FIGURE 2. Overview of the fractured end of the thermowell housing looking toward the fitting and the fractured fillet weld joining the fitting to the pipe.

Structural Integrity (SI) was recently asked to examine a fractured thermowell and determine the damage mechanism. The thermowell had been removed from bypass line piping in a heat-recovery steam generator (HRSG) that ran from the High Pressure (HP) bypass valve to the cold reheat section, and sent to the SI Materials Science Center. As reported by plant personnel, the fracture was located within the pipe wall. The pipe material was specified as ASME SA-335, Grade P22, and the thermowell was specified to be ASME SA-182, Grade F22.

Examination Procedure and Results

The fractured thermowell sections were visually examined and photographed in the as-received condition, as shown in Figure 1. The thermowell was comprised of two pieces: the thermowell housing itself which protruded into the steam stream, and a fitting connection to the pipe into which the thermowell housing was inserted. The fitting was fillet-welded to the pipe. Areas on the fitting and the housing were analyzed using X-ray fluorescence spectroscopy (also known as PMI), and the nominal compositions of both components were consistent with Type 316 stainless steel.

The thermowell housing had fractured below the fillet weld at a diameter transition, reportedly within the opening in the pipe wall. In addition to the fracture across the thermowell housing, the fillet weld was partially fractured and contained a crack that was visible on the surface that had been cut for sample removal. These features are shown in Figure 2.

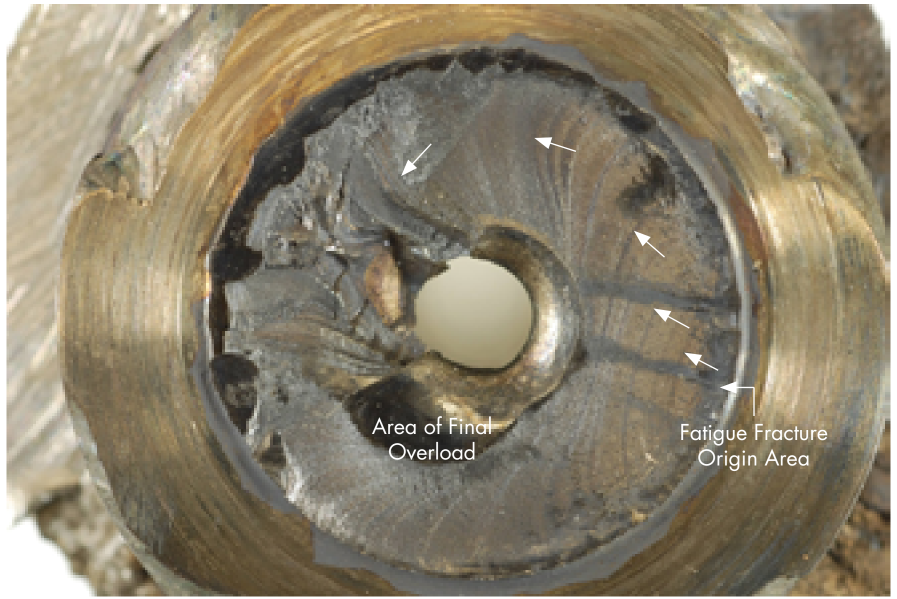

FIGURE 3. The thermowell fracture surface on the thermowell fitting section. Beach marks (white arrows) across the fracture surface are evident. The beach marks show the direction of fatigue crack propagation, which goes around the center hole.

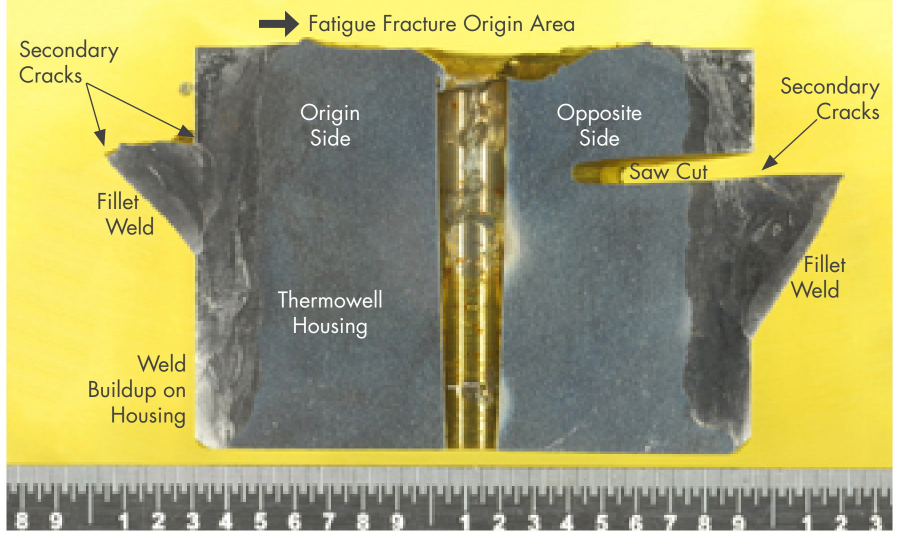

FIGURE 4. The prepared cross-section through the fracture on the fitting side. The heavy black arrow indicates the direction of fatigue crack propagation. Note that the pipe wall would be at the top of this image.

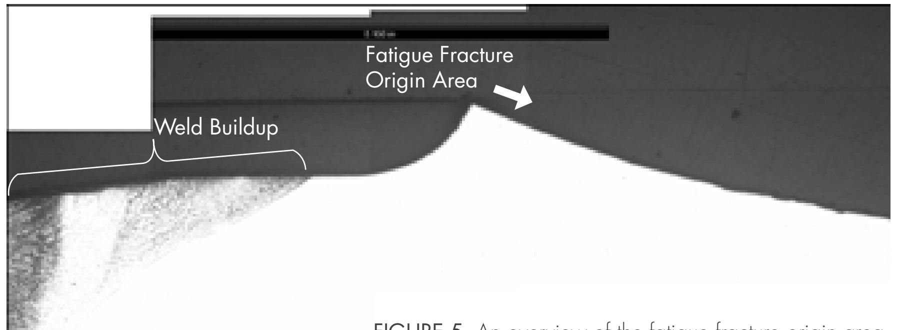

FIGURE 5. An overview of the fatigue fracture origin area. The fracture across the thermowell housing surface was relatively flat and smooth. The arrow indicates the direction of fatigue crack propagation.

Figure 3 shows the thermowell housing fracture surface, which exhibited crack progression markings (“beach marks”), indicative of high-cycle fatigue crack growth, across the fracture surface and around the center hole. The fatigue crack origin area was located at the external surface of the thermowell housing adjacent to the weld buildup. The area of final overload was associated with the center hole in the thermowell housing; this hole was rounded and enlarged at the fracture plane, indicating movement of the housing relative to the thermocouple element that ran through the center hole. The center hole remote from the fracture did not exhibit similar damage. The housing fracture origin area exhibited relatively severe secondary mechanical damage.

The section of the thermowell containing the housing and fillet weld fractures was cross-sectioned through the housing fracture origin area. The cross-section was mounted, prepared for metallographic examination using standard laboratory techniques, and examined using a metallurgical microscope for evaluation of the housing and fillet weld fracture morphologies. The prepared sample is shown in Figure 4. The length of the housing contained in the metallographic mount had weld buildup around its outer surface, and the fillet weld was connected to this weld buildup.

Cross-sectional views of the thermowell housing fracture are shown in Figures 5 and 6. The fracture was relatively smooth and flat, which is consistent with fatigue. No secondary cracks or corrosion were observed at the origin area; however, small, secondary cracks were present along the remainder of the fracture surface. These secondary cracks were more numerous and larger on the side of the fracture opposite the origin area.The secondary cracks had an appearance consistent with stress corrosion cracking (SCC).

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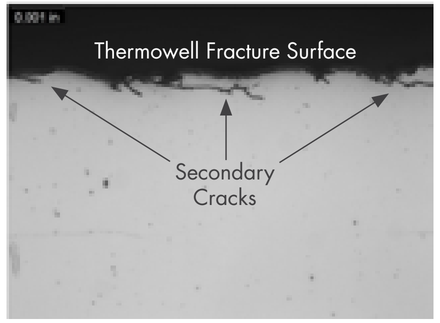

Figure 6. The small, secondary branched cracks that were present along the fracture surface outside of the origin.

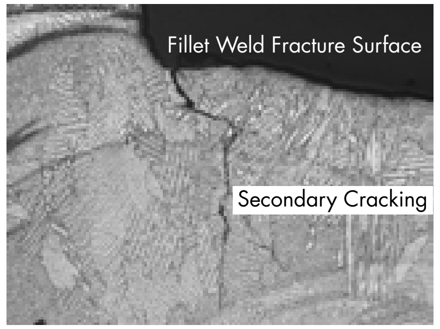

Figure 7. An example of the branched cracking emanating from the fillet weld fracture

Secondary branched cracks were also present in the fillet weld at the locations indicated in Figure 5 (page 17); an example of the fillet weld cracking is shown in Figure 7. The branched cracks propagated across the dendrites of the weld structure.

Following the metallographic examination, the deposits on a portion of the thermowell housing and fillet weld fracture surfaces were analyzed in a scanning electron microscope (SEM) using energy dispersive X-ray spectroscopy (EDS) to identify the elements present. Potentially corrosive contaminants identified on the fractures surfaces included chlorine (chlorides) and sodium (sodium hydroxide). While both constituents were present in minor amounts, chlorine was present in more of the areas examined.

Discussion

The thermowell failure was due to high-cycle fatigue. The thermowell housing clearly experienced fatigue crack propagation as indicated by the presence of beach marks across the fracture surface. However, secondary branched cracks were present along the housing fracture surface and within the fillet weld. The fatigue crack appears to have been the primary damage mechanism of the thermowell housing: no evidence of SCC was observed at the fatigue origin area, and the secondary branched cracks were larger and more numerous on the side of the fracture opposite the origin. The presence of beach marks across the thermowell housing with a relatively small area of final overload indicate the actual fracture was a fatigue rather than SCC failure. The fact that the center hole in the fractured area had enlarged also indicates there was movement of the thermowell relative to the thermocouple contained in it, and this movement is another indication of fatigue. The presence of SCC could have aggravated and accelerated the fatigue cracking. The SCC in the fillet weld would have been the cause of any steam leaks that occurred.

The scope of this analysis was limited to determining the damage mechanism and did not include modeling the thermowell to determine the root cause. It is worth noting, however, that avoiding fatigue failures due to flow-induced vibration was the driving force to updating the thermowell design code in ASME PTC 19.3 TW-2010. Fatigue caused by flow-induced vibration is typically affected by the following thermowell parameters: shank radius (the fatigue crack in this sample initiated from this radius), wall thickness of the shank, unsupported length of the shank (distance into the pipe and fluid flow), root and tip diameter of the shank, maximum allowable stress, and fatigue endurance limit. The fluid velocity also has a significant effect on flow-induced vibration. In this case the hexagonal thermowell housing was modified to fit into the round port in the piping, as indicated by the weld buildup on the outer surface of the housing. Many of these factors are addressed in the new code, so if it had been designed and installed under the new code, some of the parameters that likely contributed to the fatigue damage may have been different.

According to ASME, Key enhancements over the 1974 edition include:

- Expanded coverage for thermowell geometry;
- Natural frequency correction factors for mounting compliance, added fluid mass, and sensor mass;
- Consideration for partial shielding from flow,
- Intrinsic thermowell damping;
- Steady state and dynamic stress evaluations;
- Improved allowable fatigue limit definition.

Metallurgical Lab Featured Damage Mechanism

Acid Dewpoint Corrosion in Conventional Fossil Boilers and Combined Cycle HRSGs

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Acid dewpoint corrosion can occur in conventional and HRSG units in locations where temperatures fall below the sulfuric acid dewpoint temperature. This can occur when either the tube metal temperatures are below the acid dewpoint so that condensate forms on the metal surface, or when flue gas temperatures are below the acid dewpoint, so that the condensate will form on fly ash particles.

Mechanism

This type of fire-side damage occurs when sulfur dioxide (SO^2) in the flue gas oxidizes to sulfur trioxide (SO^3) and the SO^3 combines with moisture to form sulfuric acid. If the temperatures are at or below the acid dewpoint, so that the sulfuric acid condenses, then tube metal corrosion occurs. The temperature at which condensate first forms depends on a number of factors, including the partial pressures of SO^3 and water vapor in the flue gas, but is usually around 250 to 300°F.

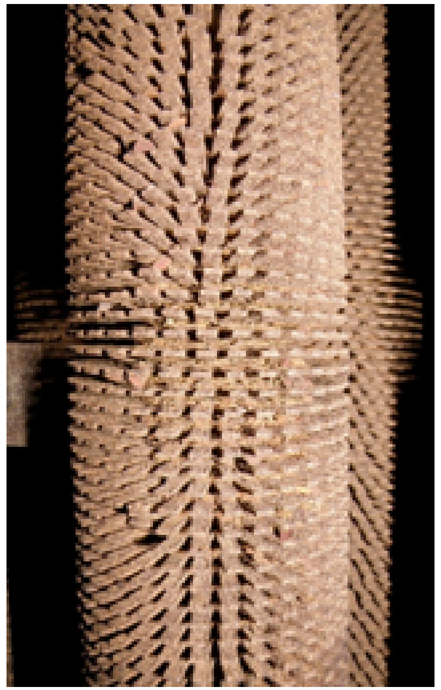
Several factors can influence the occurrence of acid dewpoint corrosion including excess oxygen, fuel firing, moisture levels, surface temperatures, and air in-leakage. The higher the level of excess oxygen in the combustion process, the more SO^2 that will be converted to SO^3 and the higher the acid dewpoint temperature. In addition to excess oxygen, other fireside conditions such as furnace design, furnace temperature, firing conditions, and burner performance will all affect the production of SO^3. For example, staged combustion, used to control NOx, can increase excess air and the amount of SO^3 produced. Air in-leakage can provide excess oxygen and cooling effects (lower temperatures).

Typical Locations

- Areas where temperatures are below the acid dewpoint temperature
- Not generally a concern for conventional unit boiler tubes; could occur in economizers if operating temperatures fall below the acid dewpoint temperature
- For HRSGs: economizers, preheater tubes

Features

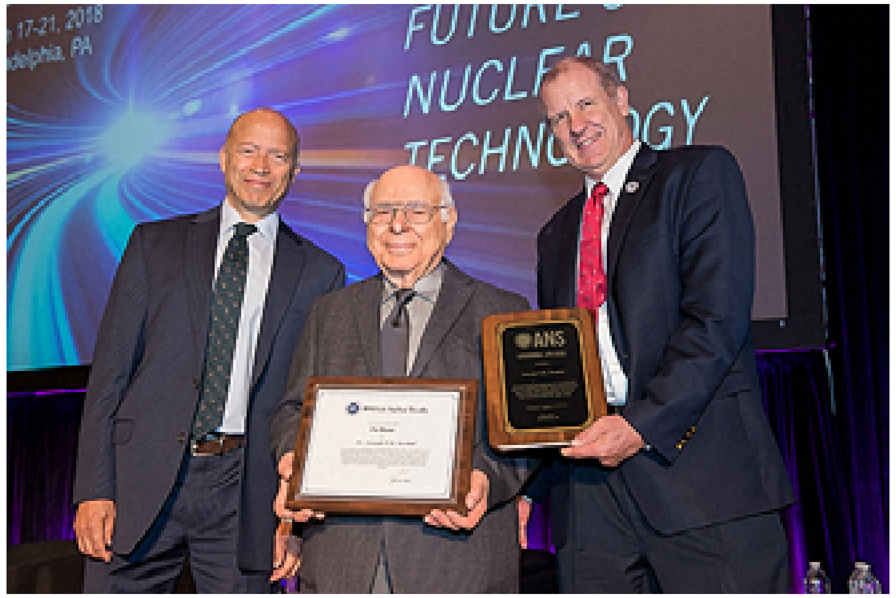
- Fireside/gas-side mechanism
- Gouged or orange-peel appearance beneath deposits
- In conventional units, the final failure occurs by wall thinning so a fracture will appear thin-edged, transgranular, and ductile
- In an HRSG, the affected tubing is at low pressure so failures are primarily pinhole leaks



LP economizer tube from an HRSG showing dewpoint corrosion.

Backpass economizer tube with wall loss due to acid dewpoint corrosion.

Dr. Joe Rashid 2018 Recipient of ANS Mishima Award

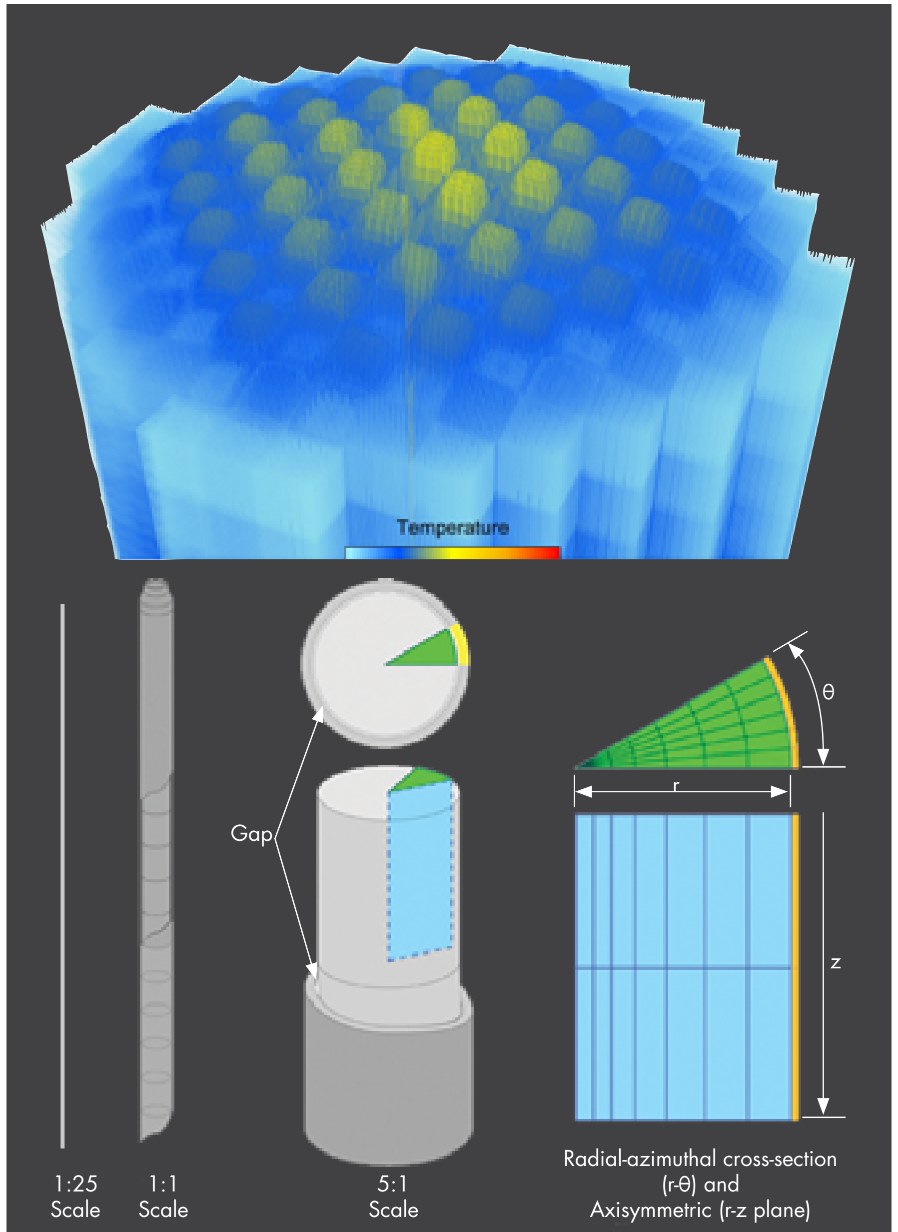


Structural Integrity is proud to employee some of the strongest, and most intuitive, minds within the industry. Dr. Joe Rashid was presented with the ANS 2018 Mishima Award, which recognized outstanding contributions in research and development work on nuclear fuels and materials.

Dr. Rashid has over 50 years of experience in the engineering analysis of complex structures. Dr. Rashid has been the principal developer of several major computer codes with widespread use within the nuclear industry. These include the fuel performance analysis code FALCON (and its predecessor, FREY). Dr. Rashid has made significant contributions to nuclear fuel safety, with numerous contributions to the technical resolution of reactivity-initiated accident (RIA) tests conducted in France and Japan. Likewise, Dr. Rashid is known for his expertise in spent fuel cask drop evaluation and is the author of the EPRI Target Hardness Methodology that has been used by many utilities. Dr. Rashid has served on numerous NRC expert panels involved with performing Phenomena Identification and Ranking Table (PIRT) evaluation associated with severe accident conditions of RIA, loss-of-coolant-accidents (LOCA) and for Boiling Water Reactors, Anticipated Transient Without Scram (BWR-ATWS).

As a contributor to the technical literature in Structural and Computational Mechanics, Nuclear Fuel Technology, and Materials Behavioral Modeling, his work is internationally recognized and spans a wide range of activities, which include: three-dimensional finite element modeling and computations, material and computational modeling of creep and plasticity, irradiated materials characterization, computational fracture mechanics, analytical modeling of nuclear fuel behavior, large scale computations in nuclear structures, identification and evaluation of damage mechanisms in spent fuel dry storage, and modeling and analysis of spent fuel subjected to the regulatory hypothetical transportation accident. Additionally, he has made widespread contributions to the analysis to ensure the safety of reactor pressure vessel and containment structures, dating to his seminal 1968 Nuclear Engineering & Design paper, Ultimate Strength Analysis of Pre-Stressed Concrete Pressure Vessels. He has authored over 200 reports and papers in these areas, including 100 papers in nuclear fuel and reactor technology.

Dr. Rashid is most widely recognized for his contributions to the development of nuclear fuel rod modeling and analysis computer codes that are widely used throughout the nuclear industry. These codes build upon his experience with finite element modeling, and include FREY and FALCON, which are still widely used in the nuclear industry now. These codes and Dr. Rashid's technical contributions provide the foundation for the modern analysis approach to nuclear fuels. Without his pioneering efforts, today's fuel performance analysis tools that are being used by the industry to enable efficient day-today operation would not have been available. His work also inspired the new, full three-dimensional tools that were developed by US-DOE in recent years. Further, the FALCON code has been the key code in the industry to analyze the experimental data for Loss of Coolant Accidents and Reactivity-Initiated Accidents that informed the current regulations in "Acceptance criteria for emergency core cooling systems for light-water nuclear power reactors" (10CFR 50.46). This represents a clear example of Dr. Rashid's contribution to the safety and regulatory approach for nuclear reactors.



Fundamental geometric modeling approach applied in Falcon

As well, Dr. Rashid has made influential contributions to the analysis of spent fuel cask drop accidents, leading to the demonstration that the upper bound of cask deceleration load is a small fraction of regulatory-target loads. This analysis has been documented in the EPRI Target Hardness Methodology (Rashid, Y. R., Nickell, R. E., James, R. J. and Zhang, L., "Validation of EPRI Methodology of Analysis of Spent-Fuel Cask Drop and Tipover Events", EPRI TR-108760, 1997). Dr. Rashid has also made significant contributions to assessing the potential failure mechanisms of spent nuclear fuel, including evaluation of the implications of cladding creep and zirconium hydride re-orientation. These contributions continue to inform the DOE program on managing used nuclear fuel.

His major contributions to the development of quantifiable strain energy density criteria to define of zirconium alloy cladding during proposed reactivity insertion accidents and to the code development and mathematical description of complex nuclear fuel rod performance during both steady state and transient power conditions are of particular usefulness to the nuclear industry.

Congratulations Dr. Rashid on the recognition for a lifetime of impact and achievement within our industry!

Life Management for High Energy Piping (HEP)

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High Energy Piping systems, including main steam and hot reheat piping, are typically very reliable and can often operate trouble-free for decades. However, due to the combination of pressure and temperature at which such systems operate, a failure can have catastrophic consequences from a safety perspective and in terms of equipment loss. Because of this and the requirements of the ASME B31.1 Power Piping code, HEP programs – or as defined by Code, Covered Piping Systems (CPS) – are established to ensure that the integrity of the system is maintained throughout their lifecycle. This article discusses the steps required to implement an HEP / CPS life management program.

A Life Management Program is not synonymous with an inspection program. Inspections are an important part of an overall program but should be complimentary to the use of analytical tools, real-time monitoring, and laboratory examinations.

There is no one-size-fits-all HEP program for steam generating plants because there is a great variety in age, design, materials, and owner objectives, but any plant will benefit from a structured, systematic approach to creating and implementing a program. This structured approach should include evaluating what current program is in place (whether formal or informal), what the objectives of the program are (short term and long term), what equipment is in place, and its history.

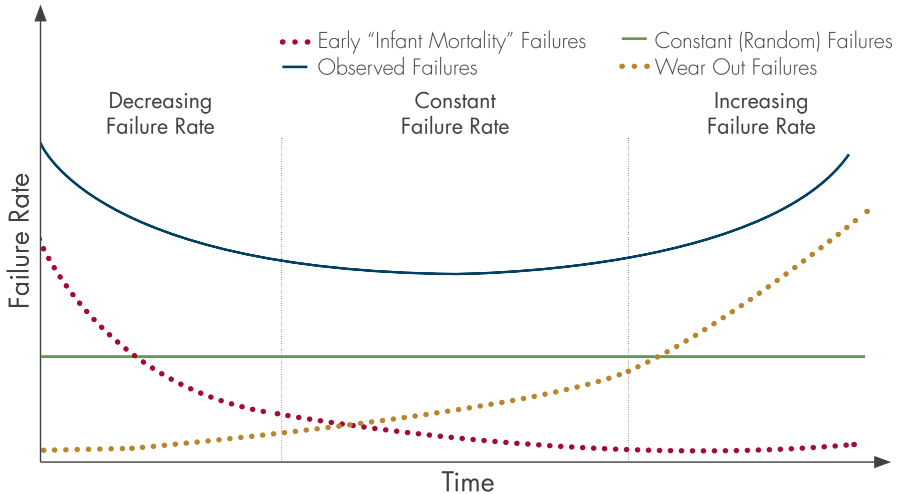

FIGURE 1. Lifecycle Bathtub Curve

HEP programs must consider the typical issues and failure mechanisms that can occur because of plant operation, as well as problems related to the original design and erection of the piping system and supports. For example, piping systems that operate at high temperatures in the creep range will ultimately suffer creep deformation, damage, and possible failure because of sustained loading at these temperatures. The damage is likely to develop at welds due to the inherent creep-weakness of the heat affected zones (HAZs) associated with them. For Grade 91 systems, a life management program must also consider possible discrepant conditions in the base metal resulting from incorrect manufacturing and heat treatment processes. The conditions include material with low strength (so-called "soft" material) and material more susceptible to creep cavitation damage due to the presence of impurity elements that are not controlled by ASTM specifications. Also, experience with such piping systems has highlighted several issues that are related to design deficiencies, such as poorly-sized fabricated branches, dissimilar metal welds in flow meters, thermowells and other connections, improper support arrangements, etc.

Each of these factors can affect the serviceability of the system at a different phase of its lifecycle with some potentially causing failures very early in life (e.g. design deficiencies), some causing premature failures (e.g. incorrectly heat treated or damage susceptible material), and some causing classic end-of-life wear-out (e.g. HAZ cracking in welds). Figure 1 provides an illustration of the failure rate over time for typical systems, commonly referred to as the "bathtub" curve due to the shape of the overall failure rate.

While many of these factors are well understood and, in many cases, quantifiable, there are always unknowns and assumptions in analyses, and limitations in the effectiveness of non-destructive testing techniques. Therefore, it is not prudent for a life management program to entirely rely on life predictions and/or inspections based only on likelihood of failure. For a risk-based program to be effective, life estimates must be combined with the potential consequences of failure, which are often expressed in a semi-quantitative form such as safety consequence, lost generation, collateral damage, and/or time to repair.

The approach described in this article for managing the integrity of piping systems is to identify locations of interest, risk-rank those locations, implement a plan for determining the health of the highest risk locations, and take actions based on the health that has been determined. The ranking and health assessment are re-evaluated at specific intervals (e.g. yearly) to ensure the program is always focused on the contributors that represent the highest risk to system integrity. Note that while this approach may include NDE inspections, the intent is to build a life management plan that goes beyond

Continued on next page

inspections. It is life management – not inspection management – of the equipment.

PROGRAM OVERVIEW

A typical program as outlined below provides a methodical and iterative approach to applying asset performance management techniques to HEP systems. It is consistent with the condition assessment aspects of the operation and maintenance requirements for covered piping systems (CPS) given in ASME B31.1, Chapter 7; follows risk-based practices such as those outlined in ASME PCC-3; and is consistent with the life cycle management philosophy developed through EPRI's international research effort into creep-strength enhanced ferritic steels such as Grade 91. It utilizes a risk-based approach for determining where to perform analysis, inspections, or monitoring and when each technique should be applied.

Fundamental phases of this approach include initial determination of vulnerabilities and prioritization, field evaluations, online monitoring, material testing, stress analysis, and refined life predictions. An underlying objective is to improve the accuracy of remaining life predictions through more quantitative analyses in subsequent iterations. The specific timing for the phasing of program elements is based in part on approximate creep life calculations that bound a window for program ramp-up, as well as known industry issues related to plant-specific design elements.

Successful implementation of a program to manage the lifecycle of HEP systems relies on integrating the elements described below. Figure 2 shows a phased approach of implementing the various elements of the program.

Phase 1 **Establish Program**	■ Gap analysis ■ Develop program guidelines & procedures ■ Initial inventory & assessment, implementation of data management program
Phase 2 **Initialize Program & Create Multi-Year Plan**	■ Prioritization & multi-year inspection/monitoring/analysis plan
Phase 3 **Program Implementation & Maintenance**	■ Online monitoring ■ Inspections ■ Stress analysis ■ Annual system health check & updated plan
Phase 4 **Program Audit**	■ Program effectiveness review

FIGURE 2. Overview of phased approach

PHASE 1: ESTABLISH PROGRAM

The purpose of this phase is to establish program guidelines to create a HEP program that lays the groundwork for implementing industry best-practices while incorporating the asset owner's objectives.

Gap Analysis/Existing HEP Program Assessment

A gap analysis is beneficial if the plant(s) has previously implemented a High Energy Piping (HEP) program and now want to assess the elements of the existing program relative to what is typical in the industry or is considered best practices. This gap analysis/benchmarking provides insights into the current program and provides a roadmap for implementing changes (if required). If no program has been implemented, this step may not be necessary.

The assessment should include:

- Review existing HEP program tactics and goals for the plant(s)
- Verify existence and quality of documentation including:
  - System design and inventory
  - Inspection history
  - Pipe support history
  - Operating data snapshot
- Compare with recommended HEP program fundamentals
- Develop roadmap and timing for program enhancements

The output from this effort is an understanding of the gaps between what is currently in place vs. what the program will have in place at full maturity, and a plan of how to get there.

Develop HEP Guidelines

When establishing a new program or formalizing an existing one, plant owners or operators should document the HEP guidelines that will be used to systematically predict, prioritize, and monitor service-induced damage common to the main steam, hot reheat, cold reheat, and other piping systems covered by ASME B31.1 or are included in the program due to other criteria. The guidelines should:

- Emphasize personnel safety and unit reliability
- Define the scope (which systems are to be included)
- Provide guidelines for collecting an inventory (welds, attachments, supports)
- Provide guidelines for prioritizing and selecting locations for monitoring, inspection, or analysis
- Define roles and responsibilities for program implementation
- Define how the success will be measured and audited

The intent is to clarify the features of the program and create a document that provides the framework for the HEP life management program. It should also include discussion on the necessity to prioritize locations for monitoring, inspection, or analysis, and outline the methodologies for inspection (e.g. applicable inspection techniques) and analysis (e.g. use of creep-redistributed stress analysis for components operating in the creep range).

Inventory HEP Systems and Implement Data Management System

A complete program should include creating an inventory of weld listings, spool information, and support details for the included system. This information should be gathered in a data management system or inventory database. The program should address and include the inventory items such as welds (girth, saddle, branch, longitudinal seam), supports, elbows (for which creep embrittlement has been an issue in some steels), base metal for older low alloy systems, locations where attemperators might cause fatigue, etc. Essentially, the inventory should include as much detail as possible as this information will be used to determine what material issues might exist, what damage mechanisms may be active, and what design features might be a problem.

Often, original design drawings lack weld and pipe support details necessary for evaluation and long-term management. A piping isometric drawing that provides a consistent labeling system for welds, supports, spools, and other items of interest, with location information is an essential part of a HEP Program. Such drawings are the cornerstone for communicating and implementing ongoing program tasks, so drawings often need to be developed as part of this step. Advantages are gained if the drawing is interactive with the system inventory database which allows analysts to display and manipulate data while visualizing locations.

Figure 4 provides an image from SI's PlantTrack™ software as an example of interacting with the data generated in an HEP program. In the image, welds are shown with various call-outs indicating which NDE methods are going to be used in an upcoming outage.

PHASE 2: PRIORITIZATION AND MULTI-YEAR PLAN

Prioritization and Multi-Year Inspection/Monitoring Plan

Once an inventory of welds, supports, attachments, and any other items that are included in the program has been compiled, the next step is to prioritize the components using a risk-based approach. SI has developed a risk-based inspection prioritization routine, VINDEX™, that provides a consistent, semi-quantitative approach to prioritizing welds and components for inspection based on risk. The methodology accounts for analyses that may have already been done (e.g.

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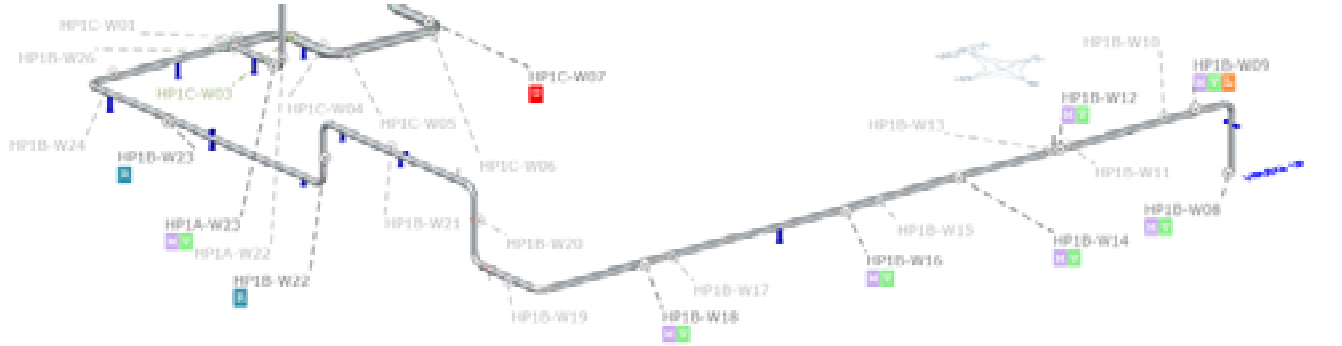
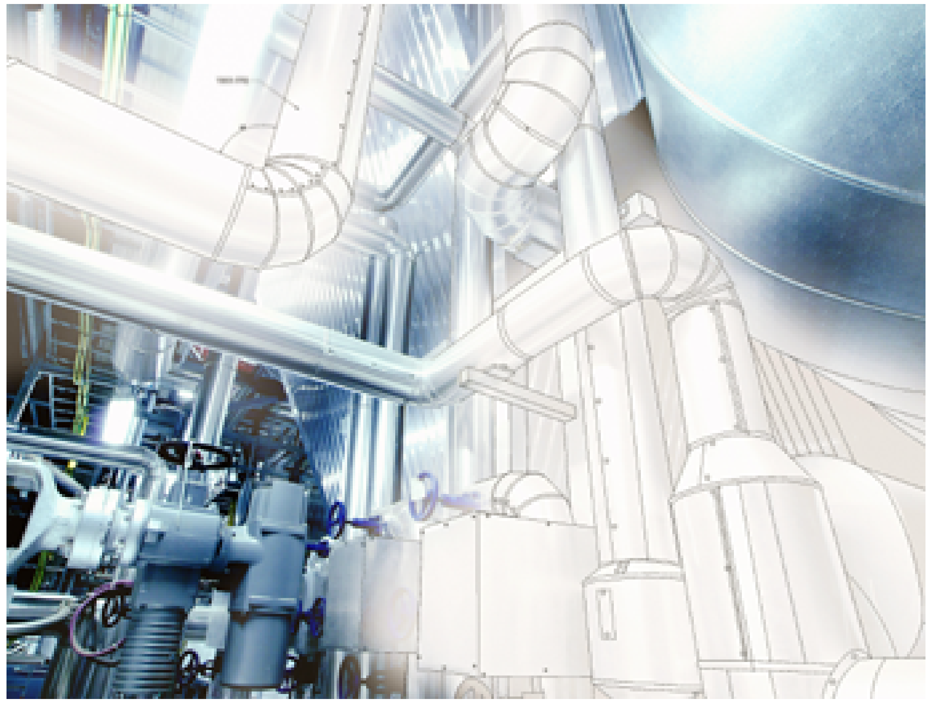


FIGURE 4 Example PlantTrack Screen Showing Welds to Be Inspected



stress analysis) and other factors including metallurgical factors, experience, inspection history, and consequence of failure based on man-pass frequency (see Figures 5 and 6). From this engineering prioritization, plans can be developed with practical approaches to inspection, detailed analysis, and monitoring of high-risk components/welds.

Available data is used for the initial prioritization. As the program matures and enters, Phase 3, more data will be collected to refine the risk-ranking models. For example, initial creep-life calculations may be based on simplified hoop stress calculations, but as the program matures, calculations may be updated with actual wall thickness values rather than specification minimums, or a detailed finite element model may be built of the system and a fully creep-redistributed piping stress analysis performed, as described further below.

PHASE 3: PROGRAM IMPLEMENTATION AND MAINTENANCE

The third phase of the program is to implement and maintain the program defined through the previous steps. It is important to realize that this phase is an iterative process in which analyses and inspections are performed to assess the condition of the components and make the run, repair, or replace decisions necessary to maintain the integrity of the systems for safety and reliability. As the equipment cycles and ages, it becomes necessary to implement various techniques to refine the risk models developed in the previous phases. The techniques are summarized below, but the order in which they are implemented is based on the results of ranking, the risk factors of the plant(s), and the long-term goals of the lifecycle management program.

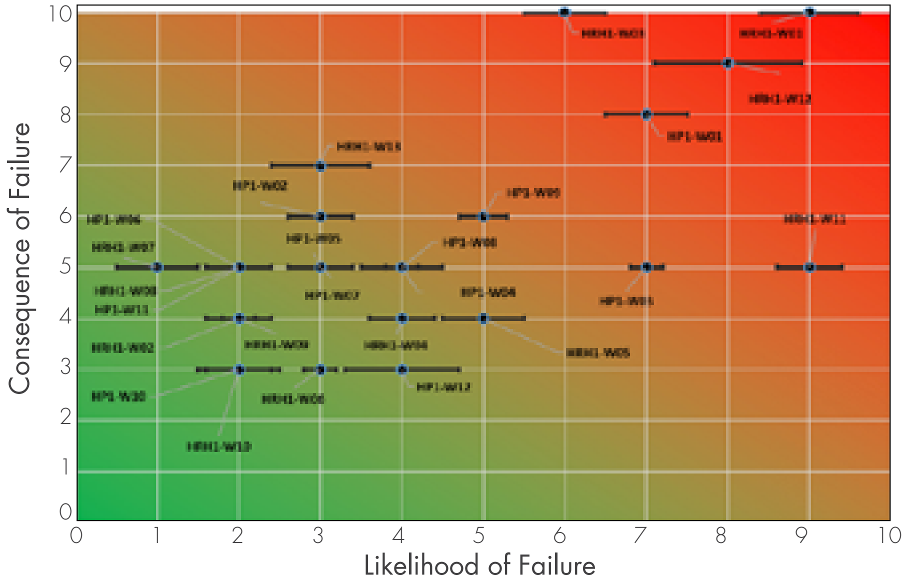


FIGURE 6. Risk as a Function of Likelihood and Consequence

Real-Time Damage Tracking/ Monitoring

It is advantageous to track the damage accumulated by the high energy piping components to gain insight into how plant operations are affecting the aging of the components. Technology is now available that allows lifing calculations to be performed in real time based on operating data already being collected in plant data historians. As an example, SI's PlantTrack software offers a suite of Online Damage Tracking Applications that provide real-time tracking of the most common damage mechanisms that are likely to cause failures in critical plant assets. This allows more accurate results, compared to an "offline" assessment made using estimated steady-state operating conditions. It also allows users to directly see the impact of changing operation on the life of critical components.

Inspections

Performing periodic Non-Destructive Examinations (NDE) at selected locations provides data that validates analyses and provides assurance that the pipe is aging as expected. The specific techniques and locations are dependent on the service hours of the equipment along with the design (e.g. material, geometry, temperature, pressure, and other loads) and health assessment that have been determined in other steps of the program. It is important that the capabilities and limitations of nondestructive inspection techniques are understood to ensure that the inspection actions that follow from the prioritization exercise will result in valid data that can be used to draw valid conclusions about the serviceability of the components, and to update the prioritizations.

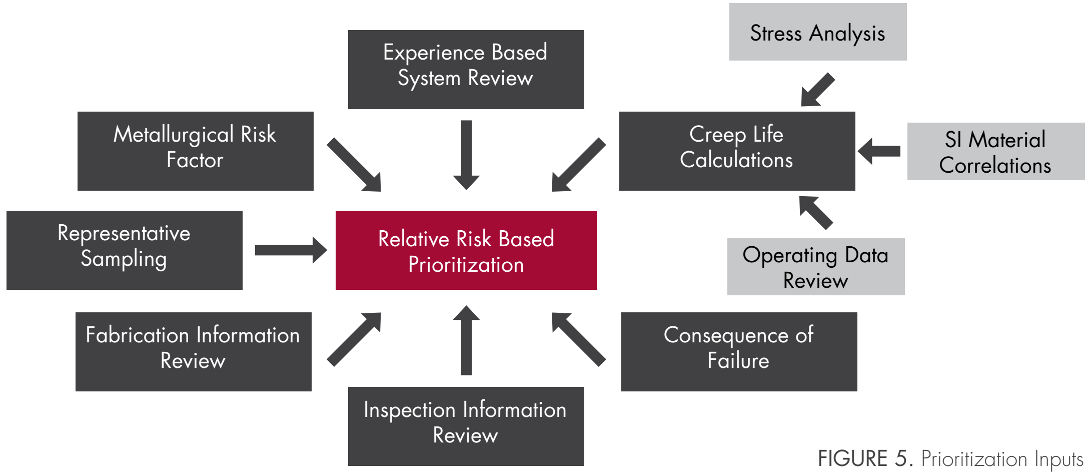


FIGURE 5. Prioritization Inputs

It should be noted that there is a significant difference in performing code inspections, which are looking for fabrication defects, and inspections for in-service damage in metals that operate at high temperature. The ASME code provides guidance on new weld acceptance but doesn't provide guidance on what is acceptable for assets that have experienced in-service, age-related damage. A previous News and Views article provides good details on the difference, and can be found here: www.structint.com/nv38/volumetric-ultrasonic-examinations.

Stress Analysis

Stress is the driving factor for creep damage occurring in High Pressure (Main Steam) and Hot Reheat systems. A typical approach to implementing a piping program is to start with simplified, closed-form hoop stress calculations. While this is usually conservative, it does not account for localized (axial) stress effects coming from thermal expansion, potential system constraints, and effects of creep relaxation. These are assessed through a full piping system stress analysis with finite element modeling.

Many plants have an ASME B31.1 code-type elastic piping stress analysis that was performed during plant design. This elastic analysis uses flexibility and stress intensification factors to approximately represent piping features, and does not account for stress redistribution due to creep deformation over the lifetime of the system. While the code stress analysis can be useful, in some cases it may not correctly rank locations susceptible to creep damage.

For those piping systems that operate at temperatures and pressures for which creep is likely to influence the operating stresses that may cause failure of "soft" material or "Type IV" damage at weld HAZs, a detailed solid-element, creep-redistributed stress analysis provides the most accurate basis for determining local stresses to provide accurate life assessments. It should be noted that some piping systems have sufficient design margins (operate at low temperatures or have excess wall thickness) such that creep is not a significant factor. For such systems the merits of performing a full-system stress analysis should be assessed; it may be more cost-effective to focus stress analysis on specific components such as branch connections or saddle welds. Other actions, such as inspection or material sampling at locations identified as potentially higher risk due to other factors (e.g. risk of soft material or due to high consequence of failure), may also provide more benefit for the same cost. Hence, not all piping systems will require detailed stress analysis.

Annual System Health Check and Updated Plan

As described throughout this article, managing the lifecycle of equipment is an iterative process. Once the program is in place, it is important to review the data that have been collected and use them to add to our knowledge of the equipment health. These data, coupled with information related to new industry issues that may have surfaced, are then used to re-consider the risk-ranking/prioritization that was done in previous tasks. Evaluations are then done to determine whether it is time to add new techniques to the program (e.g. stress analysis, etc.), or which locations should be inspected and/or monitored.

The system health check includes:

- Performing annual support walk-down of systems included in the program; reviewing findings relative to design and historical readings.
- Reviewing results from outage inspections
- Reviewing historical operational data that relates to the piping systems
- Reviewing design changes or recommended changes (e.g. plant upgrades)
- Assessing any newly discovered industry issues and their applicability and impact
- Assessing any updates to the relevant codes (e.g. ASME B31.1 chapter 7) for impact on the program
- Updating the risk ranking (Vindex) of inspection locations
- Assessing the data management system to ensure data is being entered in a timely manner and correctly.
- Updating multi-year plans with scope for repairs, replacements, inspections, monitoring, or analysis

PHASE 4: PROGRAM AUDIT

Once the program has been implemented, it should be audited periodically to determine its effectiveness. The trigger for an audit can be based on calendar time, service hours, or some other factor. The intent is to answer the following questions:

1. Is the process as laid out being followed?
2. Is the process effective?

Whether or not the process is being followed is a relatively simple matter to determine. The effectiveness of the program is harder to quantify, however. In this assessment, the goal is to determine whether the program is still performing its job of maintaining safety and reliability and whether it is structured in a way that it will continue to do so. At this stage it is necessary to review if there have been any industry failures or other best practices that should be considered. A technology review should also be included to determine if newer technology exists which should be incorporated into the program.

By performing the program audit periodically, it ensures the program is continually updated to ensure the integrity of the systems are managed using best practices while meeting regulatory requirements and the objectives of the owner/operator.

LATITUDE™ Delivers

Highlights from the First Field Deployments

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Introduction

For the past 2 ½ years, Structural Integrity Associates (SI) has been working diligently to develop, qualify and deliver the nuclear industry's first-of-a-kind manually acquired encoded phased array UT (PAUT) examination for Section XI dissimilar metal welds (DMWs). Development of the encoding technology behind this effort, the LATITUDE™ non-mechanized encoding system, was completed in 2017, with our application-specific inspection procedure completed and qualified through the industry's Performance Demonstration Program (PDI) in the Spring of 2018. Now, with much enthusiasm, we are proud to report that we have successfully completed the first field deployments of the LATITUDE technology and DMW procedure during the Fall 2018 outage season.

Background

Based on prior proof-of-concept work performed by SI that used air-coupled ultrasound to track the multi-dimensional position of a probe, SI's Strategic Development and Nuclear Engineering groups, in cooperation with and financial support from Exelon Generation NDE Services, developed a plan for further development and use of the technology as an alternative to the complex, fully-automated systems currently used for PAUT examinations of DMWs and other butt-welded piping configurations. By simplifying the inspection equipment and process through a manually encoded approach, we would be able to offer the following benefits to our clients:

- Improved inspection efficiency (decreased time) through reduced and simplified equipment combined with a customized inspection procedure designed and qualified for manual applications
- Improved fidelity of the PAUT data through manual manipulation and tactile feedback
- Lightweight portable encoding equipment that doesn't require a power or water source
- Reduced crew sizes and equipment transport, in-processing, out-processing, and setup times and lower dose
- Lower overall total cost

SI's LATITUDE technology and SI-UT-217 procedure are the result of a dedicated, "out-of-the-box", approach to innovation. Details of our LATITUDE non-mechanized encoding system and applications can be found in the related Fall 2017 News & Views article (Volume 43, pg. 32), and on www.SI-LATITUDE.com. The SI-UT-217 procedure brings a new philosophy and approach to the nuclear market for the examination of DMWs. This philosophy is based on a detection and length sizing technique that allows for rapid examination and data analysis.

The following sections provide highlights from each of three successful deployments of the LATITUDE system and SI-UT-217 procedure to inspect a total of eight welds at the Exelon Generation owned J.A. Fitz Patrick, Peach Bottom, and Dresden nuclear stations during the 2018 Fall outage season.

J.A. Fitz Patrick – 1st Implementation

The first field application of the LATITUDE system with the SI-UT-217 procedure occurred during Exelon's Fitz Patrick Station September

Continued on next page

2018 R23 refueling outage. SI was contracted to examine the N-1A-SE (~28" OD) Recirculation Outlet Nozzle to Safe End and N-2A-SE (~14" OD) Recirculation Inlet Nozzle to Safe End DMWs. Typical weld configuration can be found in Figure 1.

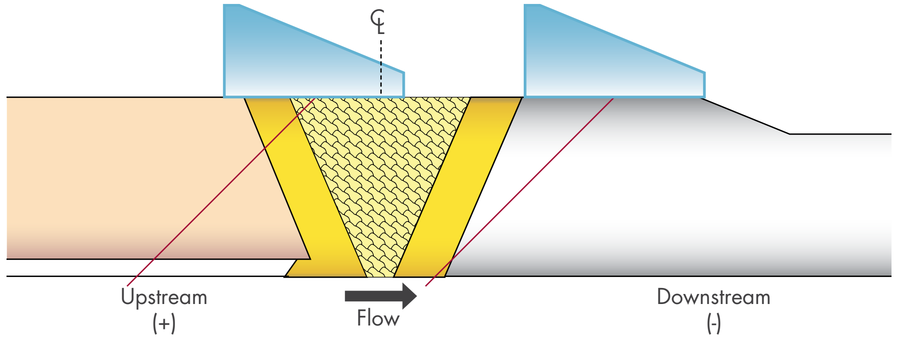

FIGURE 1. N-1A-SE

The efficiency gains from the simplified and reduced amount of equipment were immediately noticed. The inspection and encoding equipment were tested and processed into the plant within just a few hours and weld layout and setup on each weld took less than an hour each, with the setup of the LATITUDE system taking no more than 15 minutes on each weld. This reduced the total inspection evolution by at least one shift over that required for automated examinations as the time required to process in the automated equipment, set up an inspection station, run power and water hoses, and set up the equipment on the pipe can take one shift. The LATITUDE approach does not require a dedicated inspection station or the running of power cables and water hoses. Similarly, after the inspections were completed, all the LATITUDE equipment was processed back out of the plant within just a few hours, as all the equipment fits into a standard sized Small Article Monitor (SAM) when checking for contamination, saving significant de-mobilization time.

The total scan time for each weld was ~8 hours on the 28" diameter weld (N-1A) and ~6 hours for the 14" diameter weld (N-2A). This included time for calibration, scanning, switching scan configurations, etc. Considering this was the first time a manual encoded approach has ever been applied in the Nuclear industry, we were happy that the equipment performed perfectly and that the total time on the pipe for each weld was comparable to the inspection evolution for an automated system, but we knew that there was room for process improvements based on the lessons learned while scanning these two welds. It is also worth noting that no surface preparation (grinding, buffing, etc.) was required on either of the welds examined and that both welds contained an appreciable amount of hoop shrinkage, which was easily overcome through the manual manipulation of the probe.

From a radiation perspective, the N-1A had a dose rate of ~150 mREM/Hr, on contact, while the N-2A had ~420 mREM/Hr, on contact. The station's radiation dose plan called for a maximum of 3.7R for both welds and SI's total dose for these two welds was just shy of 2.4R (65% of the planned allotment), helping the station meet and even beat their dose goal for the project. It should be noted that, in the event of unexpectedly high dose rates, SI had an automated procedure and equipment on standby as a contingency.

Based on the performance of the LATITUDE system on the N-1A and N-2A welds, it was decided that LATITUDE would also be used on a UT ASME B31.1 Code examination (UT in lieu of RT) that was also in the project scope. The examination of this weld, which had a 10.75" OD and nominal wall thickness of 0.844", also represents the first successful UT ASME B31.1 code examination, using the Latitude encoded approach. The on-the-spot decision to use the LATITUDE based encoding system demonstrates the flexibility of the equipment, which can cover a range of pipe diameters with a single collar and is compatible with a variety of commonly used probes in both DMW and similar metal weld techniques.

Peach Bottom – 2nd Implementation

The second field implementation of the LATITUDE system and SI-UT-217 procedure occurred during Exelon's Peach Bottom Unit #2 R22 October 2018 refueling outage. For this project, SI was contracted to examine the N-1A (~29" OD) Recirculation Outlet Nozzle to Safe End DM Weld and an N-5B (~12" OD) Core Spray Safe End to Nozzle DM Weld. A typical weld configuration is shown in Figure 2. Similar efficiencies for testing, mobilizing, setting up and tearing down the equipment were observed at Peach Bottom as were observed at Fitz Patrick. Again, the logistics are greatly simplified by eliminating the need for a dedicated control station or to run up to several hundred feet of water hose and cabling.

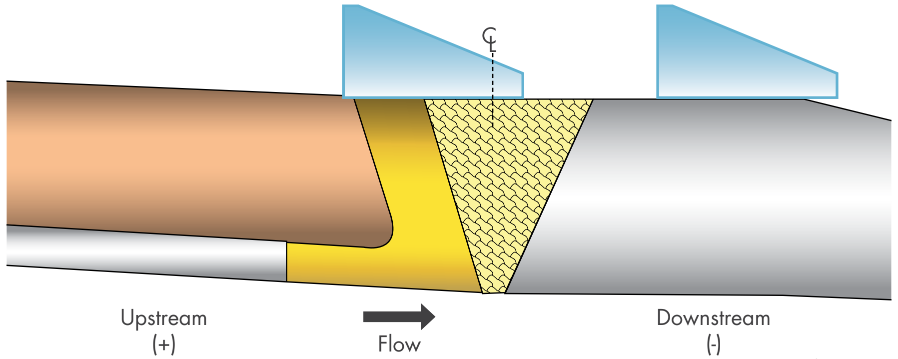

FIGURE 2. N-1A Peach Bottom

With experience from Fitz Patrick and by modifying the inspection process based on the lessons learned there, the actual total scan times at Peach Bottom were 3.95 hours for the N-1A and 1.6 hours for the N-5B, a significant improvement over the performance at Fitz Patrick on two comparably sized welds. The lessons learned included different activities related to pre-planning prior to entering containment, properly preparing the work area for access conducive to manual scanning, improved lighting, improved UT instrument usability, and an improved workflow to minimize personnel swaps and movement. Furthermore, with the hours of scanning experience from Fitz Patrick, the inspectors were more efficient at scanning at Peach Bottom.

Again, from a dose perspective, the N-1A had a dose rate of ~150 mREM/Hr, on contact, while the N-5A was ~700 mREM/Hr, on contact. The station's radiation dose plan called for a dose goal of 2.2R for both welds and SI's total dose for these two welds was 1.45R, ~65% of the allotted dose for the project. This was a significant achievement given that it also marked a notable improvement over that achieved at Fitz Patrick, even with one of the pipes having a higher dose rate, and again provided the site with a net dose savings on the project to help with achieving their overall outage goal.

Dresden – 3rd Implementation

The third implementation of the LATITUDE system and SI-UT-217 procedure occurred during Exelon's Dresden Unit #3 R25 October 2018 refueling outage. SI was contracted to examine 4 different welds. They are as follows: the RHV System - Closure Head Flange to Pipe DM Weld (4.5" OD), the N8 Closure Head Nozzle to Safe End DM Weld (5.5" OD), and the N18A and N18B Closure Head Nozzle to Safe End DM Welds (both 7.5" OD).

While officially considered the 3rd implementation of SI-UT-217, these welds are considered within the small-bore population and therefore the Dresden scope of work could be considered as another first-of-a-kind application. The N8 and N18s are located on the reactor pressure vessel head and the exams were performed while it was on the "head stand". The RHV-Closure Head vent piping weld was examined with it placed on top of the "missile shield" area, on the refuel floor. Furthermore, all the configurations on the reactor head were vertical configurations, marking the first field implementation(s) in a vertical position.

As with the Fitz Patrick and Peach Bottom implementations, the LATITUDE system and SI-UT-217 procedure performed well. With the improvements made to the inspection process that were implemented at Peach Bottom, the inspection crew was able to work very efficiently, approaching inspection rates of nearly two small diameter welds per 12 hour shift. Figure 3 represents typical data collected at each of the three plants. The dose rates in each of these locations was minimal (< 5 mREM/Hr) compared to the first two evolutions at Fitz Patrick and Peach Bottom, which were both performed in the reactor drywell. The station's radiation plan included just 90 mREM for the entire project and SI's team again came in well below this goal.

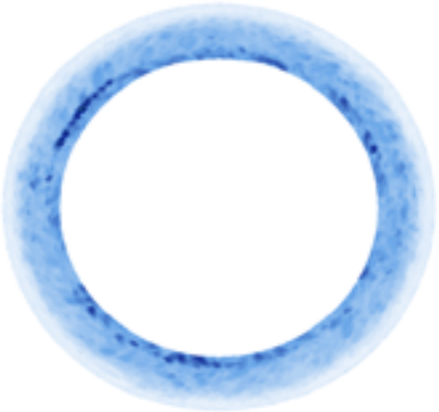

FIGURE 3. Typical acquired PAUT data utilizing Latitude

SI has successfully implemented the newly developed LATITUDE technology and SI-UT-217 procedure at three different Exelon Generation plants during the Fall 2018 outage season, marking the very first manually encoded DMW examinations in the nuclear industry. In each case, Exelon was willing to bear the risk of a first of a kind implementation and was able to realize the benefits of this new technology and procedure, saving time and cost on the overall inspection evolution and beating their radiation dose goals by significant amounts. The field team was able to overcome many real-world challenges such as hoop-shrinkage and unexpected geometry differences, delivering a quality inspection with an encoded data record at the end. Furthermore, based on the observed performance of the LATITUDE system on the DMW examinations, the system was also used to conduct a first B.31.1 code examination of a weld.

Having spent an appreciable amount on time on development, trials, and qualification, we are very excited to bring this new solution to the industry and to our customers to help improve inspection quality and reduce overall costs. In cooperation with Exelon, SI will continue to improve the overall delivery and process of the Latitude based SI-UT217 procedure. If you have questions or think you may have an opportunity to implement this new inspection approach, we are happy to discuss the technology and our experience further.

Gas Pipeline Safety Regulation Update

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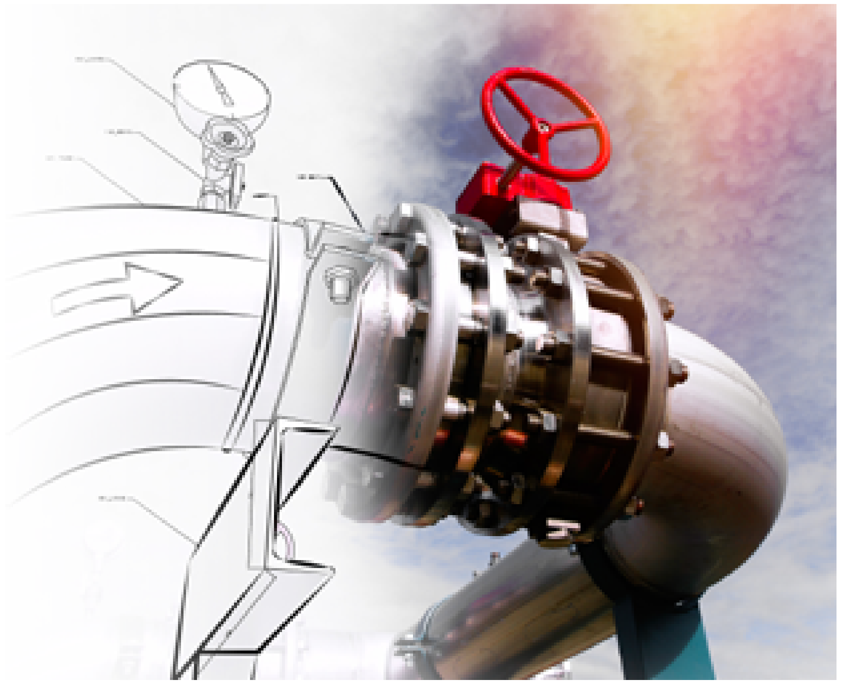

Update on the Safety of Gas Transmission and Gathering Pipelines Rulemaking (known as the Mega-Rule)

Structural Integrity (SI) personnel have had significant involvement in the Gas Pipeline Advisory Group (GPAC) meetings focused on consideration of the proposed pipeline safety rule titled “Safety of Gas Transmission and Gathering Pipelines” (Notice of Proposed Rule Making April 8, 2016). The meetings produced several recommendations to the Pipeline and Hazardous Materials Safety Administration (PHMSA) that are likely to be included in the Final Rule. A key outcome of these meetings was that PHMSA has decided the Final Rule will be split into three sub-rule packages that will all be final rules to facilitate the rulemaking process:

1. Maximum Allowable Operating Pressure (MAOP) reconfirmation, Material Verification, Expansion of Integrity Management Assessments Outside of High Consequence Areas (HCAs) and other related issues,
2. Repair Criteria, Inspections Following Extreme Weather Events, Corrosion Control improvements, Management of Change; and
3. Expansion of Part 192 regulations to include additional Gas Gathering Lines.

Industry expectation is that the first of these packages will be released in the first half of 2019. The following are some of the major elements anticipated to be included in the first package:

- Definition and new Integrity Management assessment requirements for Moderate Consequence Areas;
- Definition of Transmission Pipelines, Distribution Centers, Dry Gas, and Segments that can Accommodate passage of In-Line Inspection devices;
- Requirements to complete Material Verification (§192.607);
- Requirements to complete MAOP Determination and Reconfirmation (§192.619 and §192.624);
- Expanded record requirements.

Note that this is only a partial, high-level list of elements likely to be included in this first rulemaking. Once the first package is published in the Federal Register, Structural Integrity will be hosting a 2-day workshop to review the implications of this regulation on operators. Visit www.structint.com for More Details.

Class Location Change Requirements – Proposed Revision

On July 31, 2018 PHMSA issued an Advance Notice of Proposed Rulemaking (ANPRM) requesting comments on existing requirements for gas transmission pipelines following population growth. The ANPRM asks respondents to comment regarding additional options for operators when faced with class location changes triggered by population changes.

Class locations affect gas transmission pipelines and are important to determine MAOP; design pressure; pipe wall thickness; valve spacing; HCAs, operation and maintenance inspection and patrol requirements. Under current regulations, operators are required to replace, perform a pressure test, or derate transmission pipelines to a lower operating pressure should a class location change due to a population increase occur (§192.611). Class location concepts affect 28 individual sections of the Code.

Structural Integrity has significant depth and expertise in pipeline safety regulations and dedicates substantial resources to ensure a comprehensive understanding of proposed rules. Using the most current insights relative to upcoming regulations, Structural Integrity frequently consults with clients to help implement a strategic direction that will best position their pipeline safety programs to comply with the new regulations.

Interval Relief from RPV Threads in Flange Examination Requirements

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ASME Code Section XI requires that the RPV Threads in Flange component (Category B-G-1, Item Number B6.40, see Figure 1) be inspected each inspection Interval using volumetric examination. However, there is general agreement that the inspection does not contribute to the overall safety of the RPV. Industry experience indicates that these examinations have not been identifying service-induced degradation and that they have negative impacts on worker exposure, personnel safety, and outage critical path time. Savings from the elimination of this inspection can be applied to other more meaningful inspections of other more risk-significant plant components.

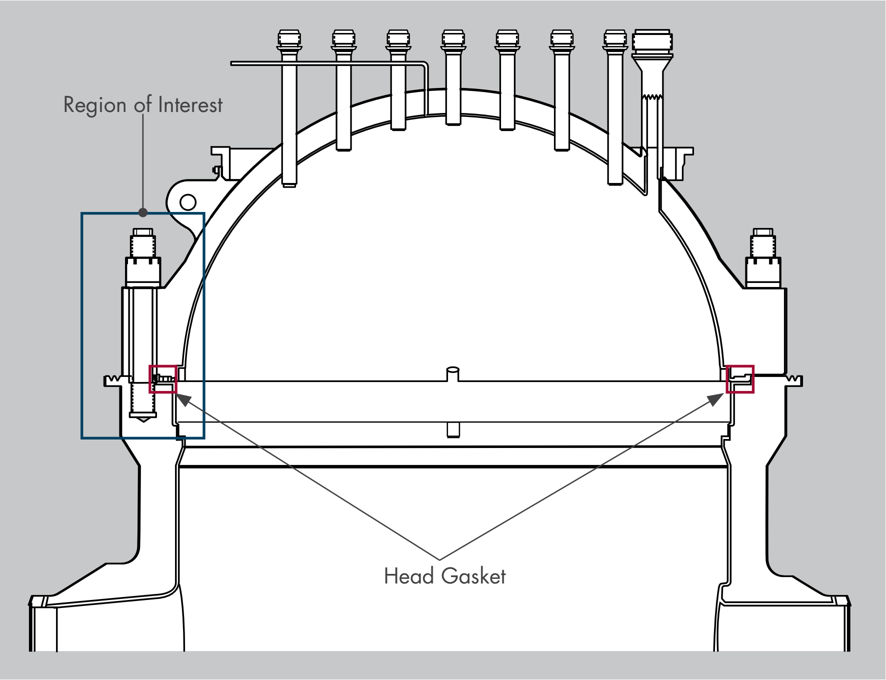
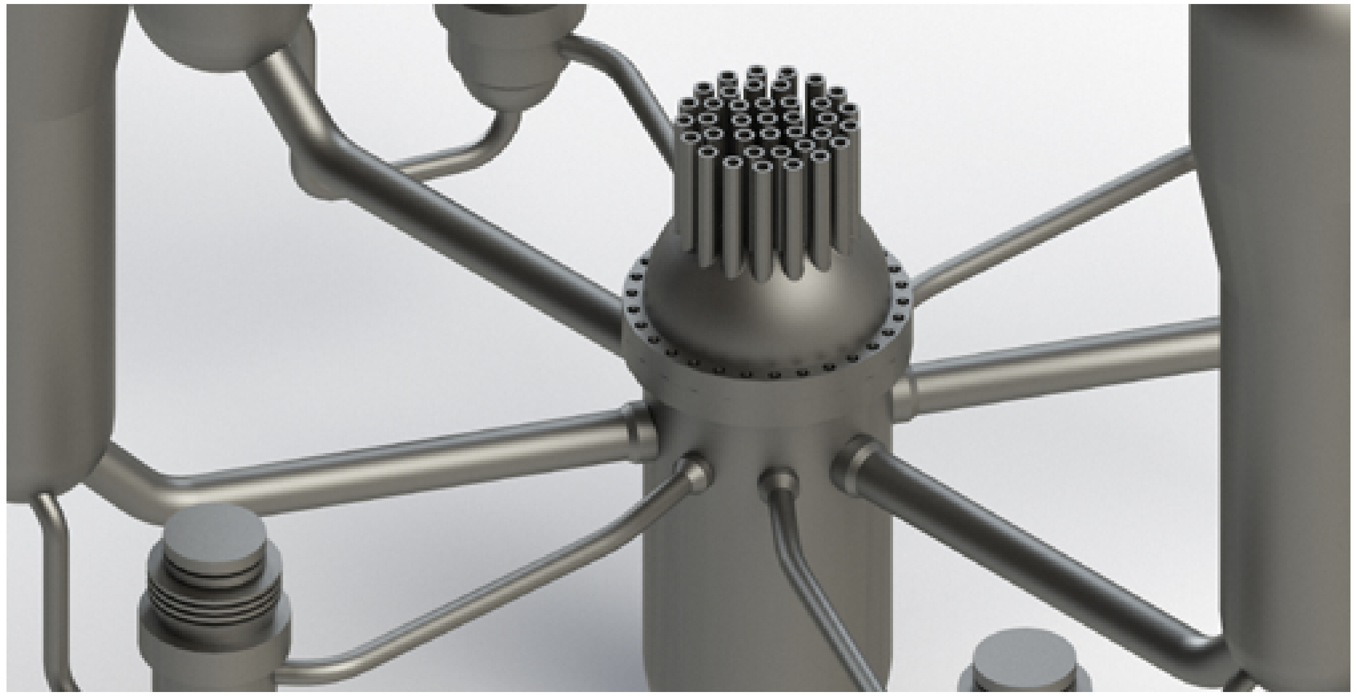


FIGURE 1. RPV Threads in Flange Component

EPRI Report 3002007626 (March 2016) provides the basis for eliminating the RPV Threads in Flange examination requirement. This report includes the results of an industry survey in which 168 units provided the status of their RPV Threads in Flange examination, as well as insight into the impacts of conducting these examinations. A literature search conducted as part of the report did not identify any related operating experience (OE) impacting the position that the RPV Threads in Flange examination requirement is providing insufficient value to outweigh the negative impacts associated with performing the examination. In addition, a degradation mechanism evaluation was performed to identify mechanisms that could potentially degrade the RPV Threads in Flange component while in-service. Potential active degradation mechanisms were then considered in a flaw tolerance evaluation to determine how long it would take a postulated flaw to challenge the integrity of the RPV.



Utility	Plant
Southern Nuclear	Vogtle 1&2
Southern Nuclear	Farley 1&2
Dominion	NAPS 1&2
Dominion	Millstone 2&3
Entergy	ANO-2
Exelon	Braidwood 1&2*
Exelon	Byron 1&2
Exelon	Calvert Cliffs 1&2
Exelon	Clinton
Exelon	Dresden 2&3
Exelon	Ginna
Exelon	Limerick 1&2
Exelon	NMP 1&2
Exelon	Peach Bottom 2&3**
Exelon	Quad Cities 1&2
Exelon	TMI
Duke	McGuire 1&2
Duke	Catawba Unit 2
Duke	Oconee 1/2/3
Duke	Brunswick Unit 1
Duke	Robinson Unit 2
Duke	Harris

TABLE 1. Plants Granted USNRC Relief for Current Interval

*Also granted USNRC relief for a second successive inspection interval
**USNRC relief for a second successive inspection interval requested

Further, a review was conducted of several plant-specific and generic industry studies used to assess the structural integrity of the RPV. The review concluded that the RPV, including the flange, studs, and other connected components (e.g., nozzles), has large safety margins. Finally, a bounding generic risk impact assessment was conducted. The results of the assessment (which used conservative assumptions) were that elimination of the RPV Threads in Flange examination requirement has very little impact on risk.

The results of this work have already been used by 37 domestic plants (BWR and PWR) to support relief requests to remove this examination requirement for the current inspection Interval (see Table 1). Each plant performed an assessment to demonstrate that their plant Threads in Flange configuration is bounded by the EPRI Report, and this assessment was included in the request for relief. For plants that may not be bounded by the EPRI Report, additional justification may be required to obtain relief.

SI staff were directly involved in the development of the technical basis for EPRI Report 3002007626 (https://www.nrc.gov/docs/ML1622/ML16221A068.pdf), "Nondestructive Evaluation: Reactor Pressure Vessel Threads in Flange Examination Requirements" (Technical Update, March 2016). Dozens of domestic plants have already taken advantage of this work, but the work can help all plants (domestic and international) remove a critical path examination with associated personnel safety and dose issues from future outages.

For more information, contact Scott Chesworth, schesworth@structint.com.

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Structural Integrity is excited to announce the release of a **FREE PlantTrack App** for both Android and iPhones in their respective app stores. The app provides several tools for fossil and combined cycle plant specialists to manage the lifecycle of their tubes and piping. It includes calculators for oxide thickness and creep life, a tube damage mechanism guide, and easy access to current and past issues of News and Views articles. It will soon have the ability to display dashboard information for users of the PlantTrack software and submit lab sample information to the SI metallurgical lab. To download the app, visit either the Apple App Store or Android Play Store and search for 'PlantTrack'.

Combined Cycle HRSG & Piping Lifecycle Management COURSE February in San Diego, CA

Join us this **February** in **San Diego, CA** and expand your understanding of Heat Recovery Steam Generators (HRSG) and High Energy Piping (HEP) in Combined Cycle power plants, and the elements necessary to manage that equipment throughout its lifecycle. Attendees will learn about design, operation, and maintenance, with a particular focus on the potential damage mechanisms and how to avoid or mitigate them. While this course would benefit anyone interested in learning more about HRSGs and HEP, topics will be geared towards plant managers, maintenance managers, engineering managers, operations managers, corporate engineers or plant engineers. Interested in learning more?

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