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Powerful Influences

In the very near future you will be hearing much more from Structural Integrity Associates, Inc., (SI) on the spectrum of on-line monitoring tools available for the assessment and management of critical components and for use with the numerous regulatory and economic concerns facing all of us. These on-line monitoring tools provide valuable information for utilities to meet the challenges they face in the current economic conditions.

There are a number of historically significant influences on the electric power industry, some of which I have commented on in past issues of News and Views and some I’ll discuss in this issue. Not only do they influence you, but they also provide challenges to SI in meeting our commitments to providing you with effective solutions.

RECESSIONARY INFLUENCES
As discussed in the Spring Issue of News and Views the effects from 2 years of recession are continuing in our industry. Some examples of this are:
- Decline in demand for electricity for the first time since 1938
- Shrinking O&M and capital budgets for owner/operators
- Reduced in-house utility staff has been reduced and lost expertise
- Extended time between outages
- Deferred or cancelled projects are being and reduced project scopes

Yet the pressure to ensure safe, reliable, and efficient operations with the needed capacity continues to increase, so we must find economical ways to develop and deploy more effective and quantitative methods for analyses and assessments of critical components: a key driver for our Innovation Core Value at SI.

DEEPWATER HORIZON OIL RIG CONCERNS
Since the last issue of News and Views, there has been the failure of the Deepwater Horizon oil rig, the Mariner Energy platform explosion, and the ensuing environmental, financial, political and social impact on the Gulf region and to the energy industry. While we are all concerned about the failure’s impacts on the region and the oil industry, the disaster is also spilling over to the electric power industry.

On one hand, one might expect the BP oil spill to boost support for the expansion of nuclear power. Proponents of nuclear power point out it is the one generation source that can be easily scaled to meet current and future demands. It allows the retirement of inefficient and aging fossil plants and provides environmentally clean energy; no coal mining, no oil drilling and transport, no ash and no greenhouse gases. Admittedly, the long-term spent fuel storage issue still lingers since the cancellation and numerous legal challenges to the Yucca Mountain Project.

On the other hand, the BP spill could kill the expansion of nuclear power. The lesson we all learned from consulting on failures is that despite our best engineering efforts, mechanical failures do occur and accidents sometimes occur as a result. Opponents of nuclear power are already linking the oil spill to their anti-nuclear agenda. Specifically, they are projecting the BP disaster to a nuclear reactor accident. Those of us working in nuclear power or who remember the Three Mile Island accident can appreciate how damaging, to an industry and public opinion, a contained accident can be, even when the impact on the environment and public health and safety was insignificant. On the Deepwater Horizon platform, the engineered safety systems didn’t work and the environmental impacts have yet to be fully quantified.
Again, we must all find economic ways to continue to provide essential analyses and assessments of critical components without any compromises to accuracy and quality of the work products; a long standing SI commitment.

RENEWABLE ENERGY POLICY AND CYCLING CONCERNS
The current local, state, and federal energy policies are creating mandates for renewable portfolio standards (RPS). These RPSs are currently applied primarily to wind and secondarily to solar. The result is that utilities must target 10-40% of generation from renewable sources. The indications are also that the EPA will continue to set and enforce increasingly stringent emission standards. The result; forced lower emissions and challenges to maintenance and upgrades for all fossil based generation (conventional gas, oil and coal boilers, single cycle gas plants, and combined cycle HRSGs). Increased regulation and mandates for RPS and EPA standards and associated capital and OEM costs will cause an increase in generation costs and Public Utility Commissions (PUCs) will be increasingly critical of corresponding rate requests. Again, the industry will require more quantitative, engineering-based rate increase support to recover non-discretionary cost increases.

At present, renewable generation sources (wind & solar) have far less reliability and availability than conventional power generation (convention fossil, HRSGs, and nuclear) and no capacity for storing excess power to be used during periods of unavailability (except minimal pumped storage capacity). However, a significant percent of total generation from these renewable sources will be mandated and they will be second in generation priority only to nuclear plants. It is broadly acknowledged that wind and solar are not reliable due to their dependency on appropriate weather for operation; in fact they are likely to be highly variable with significant unpredictability. It is anticipated that they will experience ‘outages’ on an hourly/daily basis. With no storage capacity, the load dropped from renewable sources must be picked up by conventional generation sources. Hence, conventional plants will be forced to endure additional, and potentially, fast start cycling duty.

Furthermore, the repercussions from cycling (for fossil plants) are not simply a matter of anticipating and managing increased damage but also reduced emissions efficiency, producing a regulatory forced operating complexity counter to the original design, operation, maintenance, emissions, and rate basis. Therefore, concerns are being expressed at the highest management levels in utilities regarding the assessment of the TOTAL effects of cycling on their generation assets.

ADDRESSING THE CONCERNS
Why are these three concerns related? They are all driving ways to continue to provide essential analyses and assessments of critical components without compromise to quality or costs while reducing engineering uncertainties. An emerging key strategy to address these needs is more in-situ, real-time monitoring of just about everything including damage, emissions, and efficiency. Monitoring of real conditions to replace estimates, projections, and predictions and replacing over-conservatisms with actual component-, system-, and/or operational-specific data will reduce many of the engineering uncertainties and allow for better and more timely decision making.

Although many of our readers might not realize it, Structural Integrity has been in the monitoring business for decades. Some examples include:

- EPRI monitoring products Fatigue-Pro and Creep-FatiguePro
- High temperature strain gauging for creep strain monitoring of main steam and hot reheat piping systems in fossil and combined cycle/HRGS plants, particularly in systems fabricated from P91 material
- Developed in conjunction with EPRI the BioGEORGE™ probe system for the on-line monitoring of biological activity and MIC in water piping systems
- Permanently installed guided wave ultrasonic monitoring systems for the assessment of integrity for buried piping systems
- Evaluation and upgrading of cathodic protections systems for critical plant components.

If on-line monitoring may be of value for your assessment and preservation of critical components or for use with the numerous regulatory and economic concerns facing all of us, please challenge us to provide your solution.

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PROPOSED CHANGES TO ASME CODE

Stress Indices for Socket Welds as a Function of Weld Size

By: PAUL HIRSCHBERG
phirschberg@structint.com

Socket welds in nuclear power plant piping systems have a history of failure due to high cycle fatigue. Cyclic bending loads, typically from vibration, have caused cracking either at the weld root or at the weld toe. Previously, Structural Integrity, with funding from EPRI, conducted a testing program to measure the effectiveness of proposed changes in socket weld geometry and fabrication.

TESTING RESULTS
One of the significant results of that testing program was that if the socket weld profile was modified such that the weld leg length along the pipe side is at least double the Code minimum requirement, the fatigue life of the weld becomes approximately as good as that of a butt weld. The test results demonstrated that the fatigue strength reduction factor (FSRF) is about 37% smaller for socket welds with the longer weld leg. Many plants have been replacing or building up their socket welds in locations susceptible to vibration to the 2x1 geometry to take advantage of the improved fatigue strength. However, there have been situations where welds were built up from the Code minimum, but inspections determined that the leg length was somewhat less than twice the minimum required and the weld was not accepted as meeting the 2x1 geometry. It is not known how the fatigue strength reduction factor would vary as a function of leg length for intermediate sizes. It is also of interest to determine the effect of increasing the weld leg length on the fitting side. For example, is it possible that increased fatigue resistance can be provided by adding additional leg length on the fitting side instead of the pipe side, or can a greater benefit be achieved if they were provided on both sides?

THE OBJECTIVE
The objective of our most recent work was to develop a relationship between fatigue strength reduction factors and socket weld leg lengths, for an increased leg length on either the fitting or the pipe side. The ASME Code, Table NB-3681(a) defines a fatigue strength reduction factor as the product of C2 x K2. Fatigue Strength Reduction Factors for cyclic loading must be developed by fatigue testing. However, testing programs require a significant expenditure of time. As an alternative to a testing program, a series of finite element analyses were performed, modeling socket weld geometries of varying leg length. The results were calibrated against the available endurance test results to derive a relationship between the FSRF and socket weld leg length.

The results were the following. When the weld length is varied along the pipe side there is a non-linear distribution for C2 indices between the Code minimum weld length (1.09 tn) and twice the minimum length (2.18 tn), where tn is the wall thickness of the pipe. A bounding curve was applied to the results and fitted to a second order polynomial. This resulted in a relationship between leg length along the pipe and C2. The analysis shows that any increase in weld leg length along the pipe increases fatigue strength. However, increasing the weld leg length along the fitting does not show any benefit from a fatigue standpoint; in fact, it slightly reduces the fatigue strength of the weld.
SUPPORTABLE CHANGES:
These results indicate that changes to the ASME Code equation for the C2 index may be supportable. These changes would be the following:

- Eliminate the requirement to base the calculation on the minimum of the pipe side and fitting side weld leg lengths; use only the pipe side leg length in the calculation (as long as the fitting side leg meets Code minimum)
- Use a relationship similar to the curve fit developed from the finite element analysis to calculate the C2 index
- Reduce the minimum C2 value from 1.3 to 1.1
- EPRI is planning a testing program to confirm the results of this analysis, and provide additional justification for a Code rule change.

Structural Integrity Associates has world-leading expertise in the evaluation, management, control, and optimization of all aspects of chemistry in nuclear plant cooling water and service water systems. Our whole-of-chemistry audit and assessment programs comprehensively examine not only the fundamentals of system reaction chemistry, but the interactions between system stresses and water treatment methodologies. Our multi-disciplined focus uniquely captures all the performance, efficiency, reliability, asset integrity, and life-management information that plant owners require if they are to accurately and proactively monitor the impact that system chemistry has on essential plant operations.

Structural Integrity’s capabilities for cooling and service water system chemistry include:

- Detailed technical assessment of plant chemistry performance, and the effectiveness of the chemistry in maintaining high-reliable, efficient, and clean cooling and service water systems
- Evaluation of water treatment programs, including water treatment service provider programs
- Water treatment optimization, including biofilm monitoring and control
- Process performance modeling
- Management of fouling and degradation mechanisms
- Corrosion mitigation: repair and replacement recommendations, including detailed designs as required
- Assessment, prevention and control of microbiologically-influenced corrosion (MIC)
- Condenser and heat exchanger inspections
- Scale and deposit analysis, failure analysis, and detailed metallurgical assessments
- Legionnaires’ disease risk assessment and control management programs
- Operational support
- Technical training

Cooling water and service water systems are integral to the safe and reliable operation of all nuclear plants. The water chemistry of these systems is the primary factor controlling corrosion, scale, suspended solids fouling, and microbiological fouling; the mechanisms that can seriously degrade plant performance and equipment condition. As well as having a direct, negative impact on the overall plant efficiency, fouling and corrosion will also impair the integrity of plant components and lead to costly repairs or even complete replacement. For facilities with cooling towers, the water chemistry controls the presence and activity of surface biofilm, which is both the main cause of microbiologically-influenced corrosion and a key link in the Legionnaires’ disease chain of causation.
The Qualification and Certification of Guided Wave Testing

By: CRAIG CHANEY
  cchaney@structint.com

There are a number of similarities between guided wave testing (GWT) and other high frequency ultrasonic testing (UT) techniques. Both technologies often use piezoelectric transducers to introduce the energy into the pipe and detect reflected signals. The majority of the techniques of GWT and UT utilize pulse echo transmission for probing and evaluating the inspection volume. Most importantly, GWT and UT rely heavily on the training and skill of the technician/engineer operating the equipment and interpreting the data to provide the best available data each technology can provide.

With that said, there are many significant differences between GWT and UT, such as wave propagation, the interpretation of the data, the meaning of the data and most importantly the range or distance of the tests. It is the relatively large GWT test range that makes it so uniquely valuable to the industry and at the same time so challenging to effectively utilize. Over a GWT range of ten feet to several hundred feet, a pipe can have many different conditions that affect the guided wave propagation, attenuation and reflection. To make sense of the large variety of potential responses returned to the guided wave instrumentation Structural Integrity Associates, Inc., (SI) has found that the GWT inspector needs not only to be well trained in the physics of guided wave propagation and operation of the equipment but potential pipe characteristics. These characteristics include understanding of the construction and coating of piping systems, degradation mechanisms that are specific to the system under test, the potential location and characteristic of the degradation and the opportunity to use supplementary or alternative technologies in assessing the piping. It’s not uncommon, and somewhat surprising to clients, that I may recommend an alternative to GWT that may be more effective to achieving the client’s assessment objectives. As useful as GWT is, it is not always suitable to use alone or at all for a given test situation.

OUR CERTIFICATION PROGRAM
Structural Integrity has recently created a GWT qualification/certification program under the purview of our Quality Assurance program that addresses these characteristics and challenges of GWT. The objectives of our program are to meet the following criteria:

- Meet or exceed any existing domestic or international criteria for GWT qualification and certification.
- Utilize traditional NDE qualification and certification principles that have been in use for many decades in the industry including three level certification scheme, performance demonstration, and requalification requirements.
- Build on and expand the qualification schemes that GWT equipment manufacturers have developed
- Integrate into the qualification program training in degradation mechanisms, design, and code requirements and how they relate and influence GWT.
- Provide training in supplementary or alternative techniques or technologies so that the most effective inspection method(s) are utilized to meet the assessment objectives and alternatives can be recognized and recommended in the field.
- Demonstration of our knowledge and skill through written and practical examination.

To the right is a comparison of SI’s qualification and certification program with international and domestic based GWT standards and practices.
STRUCTURAL INTEGRITY'S ADVANTAGE

As can be seen, our GWT qualification/certification program has a diverse curriculum of training that requires content and instructors from a number of potential organizations including equipment manufacturers, universities, consultants, and internal SI experts. This diversity in material and instructors not only provides training on a wide range of related technical information, it also provides the inspector a broader perspective in the physics, and differences in equipment and technology by being exposed to different instructors.

After providing the energy industry over 20 years of advanced ultrasonic inspection services and six years of GWT services we believe that blending time proven NDE qualification and certification principles with targeted training to address the specific challenges of GWT is the best means to help assure that not only the best GWT services can be provided but the development of an effective overall assessment strategy. We can discuss more specific details on our guided wave qualification and certification program with our customers.

<table>
<thead>
<tr>
<th>Area</th>
<th>Standard 1</th>
<th>Standard 2</th>
<th>Standard 3</th>
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What is PIMs?

Monitoring for the onset or escalation of corrosion damage is a key activity in an effective buried pipe integrity management program. Excavations around pipelines are an expensive and inherently risky endeavor. The logistics and costs escalate further when the excavations are at a regulated site or in a congested area. This magnitude of financial and logistical investment inhibits regularly monitoring of these buried piping systems over time. However, these monitored or repeated inspections are inherently valuable in that they allow the pipe condition to be trended over time and increase the sensitivity of the inspections by being able to subtract coherent noise from sequential test data.

MINIMIZING COST

One solution to minimize the cost of repeat inspections is the use of guided wave permanently installed monitoring systems (gPIMs™). These permanently installed piezoelectric transducer collars are attached to the pipe and encased in epoxy to protect the electronics from the environment with an imbilical brought to the service for easy access. Subsequent tests can be performed at any time by connecting an electronic control unit to an above ground connector box and run a test protocol to collect the data. Off shore pipelines, oil and gas operations, new nuclear plants under construction in various parts of the world are incorporating these systems during the construction phase, and older power stations are installing them on existing piping systems, particularly those which are buried.

SOLUTION

Structural Integrity Associates, Inc., (SI) has performed numerous installations of gPIMs on buried piping. Integrating gPIMs into your buried piping program can improve sensitivity of assessments, eliminate the cost of future excavations, and provide enhanced information for more effectively managing the degradation of your buried assets.

1. Coherent Noise: Responses from features in a component that is not necessarily discernable or pertinent in the trace or data.
2. gPIMs: A registered trade mark of Guided Ultrasonics Ltd.
WHAT IS PIMS?

Post Resin Cure. gPIMS are typically installed on 2 to 42" pipe diameters with custom collars for larger diameter pipe.

Polyurethane mold housing is adhered to the circuit board to ensure transducer contact and to provide protection from damage due to water, sand, backfill, etc.

Tiger Sealant adheres the polyurethane housing securely and permanently to the component.

Tape wrapping is placed over the gPIMS after installation as the final step before backfill.

Vent Tube is situated at the 12:00 position to provide ventilation while the resin is being injected at the 6:00 position.

Topside Connection Box. Standard weather proof box, mounted above ground, and is connected to the collar typically with a 50’ to 75’ cable.
Structural Integrity

Combined Cycle Plant Service Offering

Increasingly the US industry policy, environmental considerations, and economic factors are influencing the mix of current and future generation. Specifically gas plants predominately combined cycle HRSG’s, are increasingly replacing conventional coal-fired plants and being relied upon for critical base-loaded generation. Therefore, combined cycle plant availability and reliability are more critical than ever. To address this industry need SI has developed service offerings to aid with plant maintenance of this industry. SI has world recognized experts with the expertise and experience to provide the following services for the combined cycle plants:

- Level 1 Plant Assessment associated with cycle chemistry, FAC and thermal transients.
- HRSG tube failure (HTF) analysis involving the major failure mechanisms of FAC, thermal/creep fatigue, under-deposit corrosion (hydrogen damage and acid phosphate corrosion) and pitting. We specialize in identifying the mechanism of failure, the true root cause and the technically appropriate and most cost-effective solutions.
- HP Evaporator assessment focusing on analysis of internal deposits, which are vital precursors to the under-deposit corrosion mechanisms
- Grade 91 steel high energy piping Programs
- Grade 22 steel high energy piping Programs

Our combined cycle plant services are unique and thorough. We combine our years of industry leadership and expertise with on-the-job experience so you can be confident. We’ll tailor any combination of our services to meet your particular needs. Here are some services and expectations you should be aware of when assessing your needs.
1.0 LEVEL 1 PLANT ASSESSMENT

The first of our services for combined cycle plants is Level 1 Plant Assessment. The overall objective of our Level I Assessment is to assist the plant in identifying any aspects of operation of the combined cycle unit which will affect the safe operation, future availability and/or damage accumulation. It is also clearly recognized that thermal transients in HRSGs must be identified as early in life as possible to prevent thermal fatigue and creep-fatigue failures. A typical project is designed to help our clients develop the optimum cycle chemistry and to determine if unanticipated thermal transients are likely to lead to pressure part failures well in advance of the anticipated service life of the Combined Cycle Unit. With respect to the influence of thermal transients on plant reliability, the deliverable will be an assessment of whether thermal transients are possible and could be damaging.

1. One of the only ways to quantitatively assess thermal transients is to install thermocouples in the key critical HRSG areas.

2. A second stage (Level Two) could involve the power plant purchasing and installing thermocouples and operating the unit through typical operating regimes.

3. If undesirable thermal transients are confirmed through this process, our Level 3 analysis can be conducted to suggest operational, maintenance and/or design modifications that can be evaluated and implemented by the plant.

The main reasons for severe thermal transients are related to inadequate management of condensate which forms during the purge, inadequate drain systems and attemperators. Installed diagnostic/troubleshooting monitoring is used to characterize the severity and timing of the potentially damaging thermal transients and verify that the corrective actions taken were successful.

Our HRSG team’s expertise can frequently recognize and address critical construction, design and operational features without the installation of thermocouples and detailed thermal analyses. Level 2 and 3 activities in the cycle chemistry area involve assisting the organization to optimize the unit cycle chemistry (feedwater, drum treatments), developing adequate total iron monitoring processes, and ensuring that a fundamental level of instrumentation is in place that is alarmed in the control room. We use the cycle chemistry guidance documents from IAPWS (www.IAPWS.org) which are regarded as the world standards for instrumentation and volatile treatments. Level 2 and 3 activities in the FAC area involve identification of the areas in the low pressure circuits where FAC may be active. Rectification of FAC involves optimizing the cycle chemistry throughout the plant and ensuring that the total iron levels match the SI “Rule of 2 and 5” (< 2ppb in the feedwater, <5ppb in each drum).

To date, we have performed over 25 Level 1 assessments for domestic and international combined cycle customers both.
2.0 HRSG TUBE FAILURE PREVENTION AND ANALYSIS
A second service offering we provide to fossil plants is addressing HRSG tube failure (HTF) at any level of detail within the life cycle. Analysis and prevention aspects you should consider are:

1. Mechanism identification through destructive metallurgical analysis (see below for our destructive examination protocol)

2. Full Root Cause Analysis for HRSG Tube Failures (HTF), including identification of appropriate corrective actions to eliminate repeat failures

3. Inspection services, including internal tube, header and drum inspection (visual and fiber optics), surface inspection (VT, PT, MT, ECT), volumetric inspection (various UT techniques), metallographic replication, hardness testing, in situ chemical analysis

4. Stress Analysis/Finite Element Modeling for the tube/header connections involving T91/P91, T91/P22, and T22/P22 which are susceptible to thermal, creep and corrosion fatigue

5. Remaining life assessments

6. Detailed HRSG thermal transient analyses as part of a Level 2 analysis as described under Level One Plant Assessment above

7. Cycle chemistry review, recommendations for system upgrade and optimization, support for chemical cleaning, etc.

To date SI has performed more than 75 tube failure and analysis for various customers.

3.0 HRSG TUBE DESTRUCTIVE EXAMINATION PROTOCOL
The vital part of an HRSG tube prevention program is the metallurgical analysis of the failure situation. Repairing an HTF in place and/or not removing the failure location for analysis means that there will be no identified mechanism. Without this, it is often impossible to address the root cause and solve the problem. We specialize in tube failure analysis, which usually includes the following items:

a. The tube section will be visually examined and photographed in the as-received condition.

b. The damaged area will be removed from the bulk tube section for more thorough examination, which may include examination and documentation using a stereomicroscope and/or sectioning the tube so the internal surface can also be examined.

c. If necessary, the damaged area will be examined in a scanning electron microscope (SEM) for higher magnification evaluation. This task is particularly likely for a fracture so that the fracture origin area can be evaluated and documented.

d. If corrosion is found to have contributed to the failure, corrosion products will be analyzed using energy dispersive X-ray spectroscopy (EDS) as part of the SEM examination. This task may include elemental mapping of the corroded area to show how any corrosive species are layered or dispersed within the corrosion products. This step may also pertain to internal oxides for high temperature failures.

e. If necessary, cross-sectional samples will be removed from the damaged area and prepared for metallographic examination of the fracture morphology, the tube surface conditions, and the tube microstructure. Hardness measurements will be made on the metallographic samples.

f. The tube material will be analyzed to determine its chemical composition. The tube chemical composition may be checked against its specification through PMI (positive metal identification).

g. We provide preliminary results within two weeks of receiving the samples and authorization to proceed with the analysis. A final report containing a description of the laboratory procedures and results, discussion and documentation of the results, conclusions and, as appropriate, recommendations, will be issued within three weeks of completing the laboratory analysis.

We have applied the above protocol to at least 20 tube samples from several combined cycle plants around the world.
4.0 HIGH PRESSURE (HP) EVAPORATOR ASSESSMENT

A fourth area of expertise is HP Evaporator Assessment. The major HTF mechanism of under-deposit corrosion includes hydrogen damage, acid phosphate corrosion and caustic gouging. These mechanisms only occur in areas where there are excessive deposits. We’ve developed a three-pronged approach to conducting these analyses and published a Deposit Map which helps organizations recognize when HP evaporators need to be cleaned. Our process also assists the development of the optimum cycle chemistry, because deposition in the HP evaporator is a direct function of the chemistry used in the lower pressure circuits which controls FAC. Our results clearly show that deposition increases with the use of reducing agents and amines in the low pressure circuits, and with the use of phosphates in the HP drum other than only tri-sodium phosphate. The following represents the protocol that we use.

STANDARD HP EVaporator tube EXamination PROTOCOL

a. The tube will be visually examined and photographed in the as-received condition.

b. The internal deposit loading will be measured in accordance with ASTM D 3483 using the glass bead blasting deposit removal technique. The deposit loading coupons will be documented before and after cleaning so the condition of the deposits and condition of the tube ID surface can be noted.

c. Bulk internal deposits will be collected from the hot side of the tube [heaviest deposit weight density (DWD)] and analyzed in a scanning electron microscope using energy dispersive X-ray spectroscopy (EDS) to identify the elements present.

d. A cross-section from the gas turbine (GT)-facing side of the tube will be removed and prepared for internal deposit evaluation, which will include optical metallography, SEM imaging and elemental mapping. This task includes measurements of the ID oxide/deposit thickness and mapping of any impurities throughout the deposit layer.

We provide preliminary results within two weeks of receiving the samples. A final report containing a description of the laboratory procedures and results, discussion and documentation of the results, conclusions and, as appropriate, recommendations will be issued within four weeks of receiving the sample and authorization to proceed with the analysis. We’ve provided this service for over 45 HRSG HP evaporators around the world.

5.0 MANAGEMENT OF GRADE 91 HIGH ENERGY PIPING

Many combined cycle units have high energy piping fabricated from Grade 91 material, a creep strength enhanced ferritic (CSEF) steel. Several problems have been identified during the service operation with this steel. Deficiencies in the processing of Grade 91 and other CSEF steels have been implicated in several well-publicized failures, forced outages, construction extensions, and premature component replacements in combined cycle plants worldwide. Recent inspections at several U.S. electric generating facilities detected a large number of improperly processed welds and components, and called into question the future reliability of similar critical components throughout the industry. The impact of deficient material can be severe:

- System failures can be catastrophic
- Replacement material is difficult to procure
- Refurbishment of major components requires serious disruption of plant operation.

The reasons for these problems have largely stemmed from a failure to properly control critical aspects of the thermal processing of the material, including welding pre-heat, heating to straighten or align parts, and, in particular, the PWHT operations.

Continued on next page
NEW (YET TO BE CONSTRUCTED) PLANTS
For new plants, we focus on the complete elimination of any deficiencies in either design or processing so that when the equipment begins service the owners can have full confidence that the material will perform as intended by the design. We’ll assess:

a. Initial design review. The purpose is to verify the technical soundness of such decisions as alloy selection, maximum design temperatures in heat transfer areas, Dissimilar Metal Weld (DMW) design and location, etc.

b. Control of material procurement, to include specification of optimum chemistry and heat treatment (i.e., tempering parameter appropriate for the specific application intended) and, as appropriate, supplier surveillance, including inspection and testing, to verify compliance with all critical requirements.

c. Where appropriate, creation of a fabrication specification, to include development of new or approval of existing procedures for welding, bending, heat treatment, etc. We will assume responsibility for QA surveillance of the fabricator, including inspection and testing, as necessary.

d. When requested by a client, we will also assume total fabrication responsibility for piping and other thick-walled components, with all required inspection, testing, etc.

e. Where an outside contractor will install the components, the creation of a construction specification to include development of new or approval of existing procedures for welding, bending, heat treatment, etc. We will assume responsibility for QA surveillance of the fabricator, including inspection and testing, as necessary.

f. When requested by a client, we will also assume total fabrication responsibility for piping and other thick-walled components, with all required inspection, testing, etc.

g. Development of a comprehensive baseline data package, which will fully document for the client the acceptability of all material as installed and which will serve as the basis for subsequent life assessment monitoring.

We have performed several aspects of this program for more than 20 customers. In addition, we just signed a contract to apply the entire program to a renewable energy plant in which P-91 material is the primary piping material.

EXISTING PLANTS
For existing units, we focus on an initial material characterization, followed by implementation of any remedial action that may be necessary, and culminates in the development of a life management strategy that is tailored to the equipment owner’s commercial objectives. Typical steps in our program are:

a. Determination of the existing condition of critical components based on review of certified material test report (CMTRs), fabrication records, and construction records, supplemented by inspection and testing, as necessary. As part of this step of our program, a comprehensive baseline data package is assembled, which documents for the equipment owner the current condition of all installed material, and which then serves as the basis for subsequent life assessment monitoring.

b. Implementation of an overall life management approach for the CSEF steels in an existing plant, including development of a risk based prioritization of evaluation locations, application of the appropriate NDE techniques to detect the onset of damage, remaining life assessment, and creep fatigue monitoring, including, where appropriate, instrumentation to measure creep strains.

c. Repairs or replacements of components with deficient properties that would compromise unit reliability.
6.0 MANAGEMENT OF TRADITIONAL GRADE 11 AND GRADE 22 FERRITIC STEEL PIPING

Part 6 of our process entails management of Grade 11 and 22 Ferritic Steel Piping. Depending on the design conditions of the plant, some high energy piping for combined cycle plants may be fabricated from the traditional Grade 11 or Grade 22 ferritic steel. Although the fabrication of these steels is not as challenging as the Grade 91 steels, they are susceptible to in-service damage mechanism such as creep and fatigue. Our approach to effectively manage high temperature high energy piping (HEP) systems fabricated from Grade 11 and Grade 22 steels is to employ a fully integrated, multi-disciplined approach. All the necessary technical disciplines are used to develop and implement a program intended to help ensure safe and reliable operation of critical piping components. Structural Integrity’s HEP programs for piping of these traditional alloys involves three important steps that are fundamental to any component management program, and effectively minimize the overall risk associated with HEP at any plant.

1. The first step involves determining which locations have to be examined. To this end, SI has developed Vindex, a semi-quantitative approach to selecting and prioritizing critical pressure part welds for evaluation. The Vindex analysis uses stress information, materials knowledge, inspection data, fabrication process information, and other readily accessible data. Our analysis provides a list of the system welds in a rank ordering of the potential for damage and shows the welds that are the highest contributors to overall risk.

2. Having selected the most critical components to examine, we then determine how the selected locations should be examined. We use advanced nondestructive examination (NDE) techniques that are specifically designed to detect and quantify the damage mechanisms associated with high energy piping systems. Our NDE techniques are capable of detecting damage at an early stage in its development (as compared to traditional inspection methods), which allows for longer re-inspection intervals and extended time to develop corrective action plans.

3. Finally, we determine how to address indications that are identified during the NDE examinations. We use state-of-the-art analytical tools including fracture mechanics, life consumption analysis and risk optimization to predict future serviceability and facilitate run/repair/replace decisions. We provide recommendations for re-inspections and repairs as necessary and can assist in the performance of the repair activities. This comprehensive program is also integrated with a database to help the organization manage all the piping program data.

Our expertise in this particular service offering dates back more than 20 years during which we have served numerous customers both in combined cycle and conventional fossil plants.
Support for Achieving Life Beyond 40 Years

In 2009, the first U.S. nuclear power plants entered the period of extended operation (PEO) by operating for more than 40 years. As of August 1, 2010, the Nuclear Regulatory Commission has issued safety evaluation reports (SERs) for 59 units and has 20 license renewal applications (LRAs) under review.

Structural Integrity Associates, Inc., (SI) has provided license renewal support for nearly all of these plants, as well as those preparing LRAs for submittal to the NRC. What many people may not know is that SI’s license renewal support doesn’t end with submittal of the plant LRA.

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**License Renewal for Operating Nuclear Power Plants**

Major Phases of License Renewal project

1. **Preliminary or Study Phase**
2. **Engineering & Environmental Work**
3. **License Renewal Application Prep.**
4. **NRC Review & Approval**
5. **Commitment Implementation**

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Plants are most familiar with the support we provide related to fatigue monitoring, IGSCC/alloy 600 PWSCC mitigation, reactor internals/RPV integrity management, and now buried piping and tank inspection programs. What people may not realize is that experience covers virtually the entire range of license renewal commitments related to the AMPs listed above. In addition, we can support one-time and ongoing inspections by:

- Developing acceptance criteria to confirm that the one-time examination was sufficient for the PEO or establish an appropriate re-inspection interval.
- Performing non-destructive examinations (ultrasonic testing, visual examination, Brinell hardness, etc.).
- Evaluating of fitness-for-service in the event acceptance criteria are not met.
- Providing engineered repairs for situations where the fitness-for-service evaluation indicates continued operability is not assured.

We have decades of experience with the prevention and control of the failure mechanisms affecting long lived structures. This experience is directly applicable to helping plants meet their license renewal commitments.
We can help minimize the impact on plant staff by gathering needed design inputs, performing on-site examination of closure packages and walkdowns through mock audits using NRC inspection procedures, providing NDE support and providing a site interface for work being performed in our offices.

**EMERGING ISSUES**

We have been actively involved in supporting plant license renewal commitments on an emergent basis as well. The types of emerging issues we recently helped plants with include:

- Providing supporting evaluations and strategies in order to meet the revised pressurized thermal shock (PTS) Rule [10CFR50.61].
- Managing and predicting embrittlement in PWR and BWR vessels.
- Revising P-T limit curves, and assisting utilities with their programs for management of aging in BWR and PWR internals.

As more plants reach the end of their current license period, the commitments made years ago are coming due and addressing these areas in an orderly way will avoid the last minute rush and instead get these done in time and in a cost-effective manner.

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**STRUCTURAL INTEGRITY’s SUPPORT**

We have supported utilities in many ways, from providing assistance with developing plans for meeting license renewal commitments, performing third party reviews of aging management programs developed to meet commitments, to developing a multi-year strategic plan well in advance of the PEO. One example where we provided assistance, guidance, and plans to meet license renewal commitments, included the following work:

- Fatigue analysis of reactor coolant pumps, motor operated valves and pressurizer relief valves.
- Assessment of environmentally-assisted fatigue effects of selected plant components.
- Engineering evaluation for Control Element Drive Mechanism (CEDM) / Reactor Vessel Water Level Monitoring System (RVLMS) housings.
- Fatigue evaluation of reactor vessel internal (RVI) components.
- Engineering evaluation of reactor coolant system (RCS) hot leg sample lines.
- Fatigue evaluation of safety injection piping including the effects of thermal stratification.
- Additional evaluation of low cycle fatigue on the feedwater system, surge line and charging/letdown lines.
- Sample inspections of buried auxiliary feedwater (AFW) and diesel fuel oil (DFO) piping.
- Analysis of thermal embrittlement of cast austenitic stainless steel (CASS) components.
- Determination of delta ferrite content for components made from CASS.
- Engineering review of SCC at refueling water tank (RWT) penetrations.
Less than 12 Months for DIMP Compliance

Natural Gas Distribution Pipeline operators now have less than 12 months to comply with integrity management regulations requiring operators to develop and implement a Distribution Integrity Management Program.

Working as a collaborative group with select Northeast Gas Association (NGA) and Southern Gas Association (SGA) members, Structural Integrity Associates, Inc., (SI) has authored an industry-leading DIMP plan framework leveraged by approximately 60 firms to serve as the foundation and key building block of their DIMP plan. These organizations represent over 55% of all gas customers served in the US. As leaders in the industry, SI:

- Is currently working with several gas distribution companies to help customize their DIMP plans, project manage their DIMP implementation, and organize and analyze critical data to demonstrate system knowledge and evaluate risk.

- Recently provided basic training at the SGA operating conference to operators who are using the SGA/NGA DIMP plan framework. This training provided recommendations for the effective and efficient use of the DIMP plan framework in developing a specific distribution integrity management plan for your company.

- Has partnered with New Century Software to provide a more complete DIMP solution offering access to software tools to organize data, evaluate risk, and better present results. SI, with New Century, recently provided training to a large Midwestern gas distribution operator in support of their DIMP implementation efforts using the plan framework and software tools.

- Presented at the Western Regional Gas Conference on August 24th covering best practices and effective implementation of the NGA/SGA DIMP plan framework.

For help with your DIMP plan, give us a call, email or go to our website.

- www.structint.com/NewsandViews or contact 877-4SI-POWER or info@structint.com.
High speed rotation of large turbine and generator rotors imposes tangential stresses that are highest at the rotor axis or at the bore surface in the case of a bored rotor. This stress comprises two components, one resulting from rotation and therefore constant so long as rotational speed is maintained and the second resulting from thermal excursions. So long as the rotor is operating at constant operating conditions for sufficient time to equilibrate the temperature, the thermal stress is also constant. Major stress cycles occur only as a result of start/stop operation, during which the rotor experiences the highest thermal stress while at the same time ramping the rotational (centrifugal) stress to its highest level upon reaching full speed, with minor stress cycles resulting from load changes. Even though the stress cycles accumulated by the typical turbine/generator set are relatively low, the magnitude of the stress is relatively high. Consequently, the predominant damage mechanism is a high stress, low cycle fatigue, most likely causing initiation from pre-existing forging flaws or from link-up of forging flaws located in close proximity to one another or to the bore surface.

To compound the issues for these rotors, particularly older rotors forged prior to the advent of vacuum degassing, the steelmaking and forging practices typically concentrated inherent flaws near the shaft axis. When the ingot of molten steel is poured, it cools from the outside inward. This means that the center of the ingot is the last to solidify, and a natural circulation of the molten steel tends to concentrate any inclusions, segregates, and impurities in the last area to solidify, i.e., near the center. Additionally, the tensile shrinkage stresses are maximum at the center; consequently, any flaws formed or grown due to the shrinkage stresses are likely concentrated at the center as well. The introduction of a central rotor bore, in fact, was based on the recognition that these conditions existed and as a means of removing them.
High speed rotation of large turbine and generator rotors imposes tangential stresses that are highest at the rotor axis or at the bore surface in the case of a bored rotor.
The bore itself provides a convenient, uniform surface from which to perform periodic inspections of the central material where stresses are highest and where remnant forging flaws are most likely. The OD surface(s), on the other hand, typically involves numerous geometric features that limit inspection of the near-bore material; consequently, inspection of and from the bore surface has evolved as the preferred method for testing the surface and near-bore material for radial-axial oriented flaws that can grow under the predominantly tangential rotational stress. Inspections typically include ultrasonic procedures to detect subsurface flaws, as well as either magnetic particle or eddy current inspection for the bore surface.

### BORE INSPECTION SUPPORT
Bore inspection support involves three activities:
1. removal of the bore plug (which is shrink-fit assembled) to access the bore
2. bore honing to provide appropriate surface conditions for the inspections to follow
3. replacement of the plug upon completion of the inspection

### BORE PLUG
The bore plug is first removed by machining, and upon completion of the plug removal, precise bore dimensional measurements are made to facilitate manufacture of the replacement plug such that it is available for assembly immediately upon completion of the inspection.

### BORE HONING
Plug removal is followed by comprehensive honing of the bore surface to provide a proper surface for the inspections to follow. The ultrasonic and eddy current inspections are performed using fully automated, remotely deployed scanning devices that transport the transducers through the bore. There is no opportunity to correct for transducer lift off, tipping, and to make other similar corrections as can be done in manual inspection.

As a result, it is critical to a quality inspection that the bore surface is properly prepared to absolutely assure that all transducers can be maintained at the proper attitude and fully in contact with the bore surface.

Bore surface conditions that can prevent optimum implementation of the inspection include scale and oxide, rust, divots, scratches and gouges, and so on. At the time of the rotor manufacture, it was not uncommon practice to remove surface indications by local grinding, thereby leaving irregular, random divots in the bore surface. These are not at all conducive to an effective inspection, as they not only prohibit contact of the inspection transducers and therefore result in blind spots, but they also provide opportunities to upset the transducers. The only means to ensure an effective, comprehensive inspection is by providing optimum surface conditions.
OPTIMUM SURFACES IN MINIMUM TIME
The equipment we utilize for these services are large, heavy duty systems built to accomplish the desired result quickly. A typical honing operation requires removal of around 0.020-inch of material on the diameter, and preparation of the surface to a 60 or better µ-inch finish. Bore preparation times vary depending on the diameter and length of the bore and on the bore configuration. A bore that is of uniform diameter not exceeding five inches or so can typically be completed in two shifts. This includes the time for plug removal, honing as defined, and allowance for the time at the conclusion of the inspection for plug installation. There are no shortcuts and the only way to perform the necessary material removal requires heavy duty equipment. Hand hones and light-weight, portable systems simply cannot remove more than a couple thousandths of material in the same time; consequently, conditions that cannot be removed in reasonable time using the portable approaches typically are simply not addressed, and the inspections are subsequently conducted on less than adequate surfaces.

BORE MACHINING
In addition to these bore surface preparation services, we also provide field bore machining services. This involves even more robust machining equipment that can be used to remove greater amounts of material by enlarging the diameter more significantly either locally or over its length. Bore machining may be required, for example, to remove near-bore flaw conditions that could otherwise compromise the capability of the rotor to sustain further operation. Bore machining services may also come into use when performing certain repair welding operations that involve the bore surfaces.

Additionally, we offer miniature sample removal services to support material characterization efforts. We operate a miniature sample device that is deployed down the bore and then removes a shallow disk of material from the bore surface. The sample removal leaves a smooth, shallow dimple in the bore surface that does not negatively impact stress or surface condition and so can be left as-is following sample removal. Of course, the dimple has the same negative impact on any subsequent inspections, so must be removed at some point. Miniature samples are used to study microstructure and chemistry and to determine more precisely the fracture toughness and fracture appearance transition appearance (FATT) of the material.

For more information visit www.structint.com/NewsandViews or contact 877-4SI-POWER or email info@structint.com.
Monitoring strain on a rotating turbine-generator (T-G) shaft can provide important information to plant personnel for remaining life assessment and uprate feasibility. Structural Integrity Associates, Inc., (SI) successfully implemented a custom data acquisition system (DAS) at a hydro-electric plant to record strain values on a T-G shaft. We implemented instrumented the entire accessible shaft system with 64 strain gages (SGs) at four different elevations. These SGs measured strain in the torsional, axial, and bending senses. We utilized a custom mounting system which allowed the hardware to be mounted directly on the shaft to collect data from the SGs. Battery power allowed the system to run for up to 18 hours, continuously collecting data at 2500 samples per second, while wireless capabilities allowed it to be controlled and monitored while rotating on the shaft. This custom system allows for instrumentation and data collection from multiple types of sensors where moving or rotating parts hinder the use of cables for instrument power and data collection.
BASELINE VIBRATION DATA ACQUISITION
During the spring of 2010, we continued our support of a US nuclear power plant’s Extended Power Uprate (EPU) project. In addition to its 32-channel strain gage data acquisition system, we provided two additional systems to collect baseline accelerometer data from both inside the drywell and in the turbine building. The accelerometers were located on Main Steam, Feedwater, Extraction Steam, and Heater Drain piping, as well as on the Feedwater pump minimum flow bypass line and valve. Following data acquisition, we performed data analysis to determine the amplitudes and frequency content of the signals and compared them to the acceptance criteria (see related article in this section). The next phase of the project in 2012 should see power ascension to EPU levels.

STRAIN GAGE DATA COLLECTION FOR MUR POWER ASCENSION
In the spring of 2010, we also supported a US nuclear power plant with the acquisition of baseline vibration data for implementation of measurement uncertainty recapture (MUR). MUR is a type of power up-rate that typically increases reactor power by less than 2%. This is achieved by implementing advanced techniques for determining reactor power, including the addition of highly accurate flow meters in the feedwater line, whose readings are used to calculate reactor power. Specifically, we installed a 32-channel strain gage data acquisition system which collected vibration data related to pressure pulsations in the main steam lines. Baseline data was collected throughout power ascension, which we used in comprehensive data analysis. The results are used in a computation that will determine the likelihood of encountering a resonance condition for the expected slight increase of MUR steam flow in the main steam lines.

REVISIONS TO FEEDWATER PUMP VIBRATION ACCEPTANCE CRITERIA
At a US nuclear power plant, during startup and periods of low flow, feedwater is routed through a minimum flow recirculation line. When demand for feedwater is higher, the recirculation line control valve is closed, and all feedwater is routed through the main feedwater line. High vibration was recently measured in the minimum flow recirculation line for Loop A. Previously developed vibration acceptance criteria were exceeded when flow in the recirculation line reached approximately 8350 gpm. The previously developed acceptance criteria were based on assumptions about the nature of the vibration. Data recently obtained shows that the frequency distribution of the vibratory accelerations is significantly different from the assumptions on which the acceptance criteria were based. Data was collected during recirculation operation, partial recirculation/partial main feed operation, and full feedwater operation. The vibration levels during these three periods are different.

We performed a calculation to develop revised vibration acceptance criteria that reflects the operation of the line, taking into account the actual frequency vs. acceleration characteristics of the vibration. An assessment of the stresses in the loop A minimum flow line was performed during the three operating periods for which data was available. Since the vibration levels exceed the material endurance limit, an estimate of the allowable operating time in each condition was made. Finally, an estimate of the stresses and allowable hours of operation at a maximum recirculation flow of 9300 gpm was made.
The team of Aquilex WSI and Structural Integrity Associates, Inc., or W(SI)$^2$, completed another first-of-a-kind project with the successful overlay of a total of eight large-bore 34-inch Reactor Coolant Pump (RCP) dissimilar metal welds at the Davis-Besse Nuclear Plant in Port Clinton, Ohio. In total, 13 overlays were successfully installed during the Spring 2010 outage. This project included two 14-inch core flood nozzles and three small cold-leg drain nozzle welds.

This project accomplished several significant industry milestones:

- Large-bore RCP application far exceeded the largest pressurizer and hot leg nozzle weld overlay sizes previously overlaid (i.e., 34” vs. ~14”). Complex RCP nozzle geometry considerations were addressed with automated integrated tooling custom-designed and fabricated for the various RCP configurations and their associated interferences (i.e., proximate branch line connections, insulation fixturing, etc.). As has become standard practice for the W(SI)$^2$ team, equipment was operated remotely (from outside the reactor building) to minimize project dose.

- First approval of a license amendment request that demonstrated that the leak-before-break status of the main loop piping was preserved with the application of a weld overlay repair.

- RCP applications involved substantial welding on cast stainless materials, an issue that posed difficulty for the team on a previous reactor pressure nozzle overlay project. In summary, none of the overlays eight RCP weld overlay (or five other weld overlays) involved any rejectable UT indications.

In addition to the above, the core flood nozzle overlays involved a first-of-a-kind effort by others for cutting and creating access to the nozzles, which is just outside the reactor vessel, through the five-foot thick primary shield wall.

At the time of this writing, the W(SI)$^2$ team had just completed and demobilized from completing five (5) pressurizer nozzle weld overlays (i.e., surge and four top head safety and spray nozzle welds) for Angra-1 in Brazil. The team completed this project, in cooperation with our overall project manager and partner, Iberdola Engineering and Construction, under original schedule and dose estimates (i.e., the actual schedule of ~10 days and dose of ~9 Rem).
ABOUT W(SI)^2

W(SI)^2 is the team of Aquilex Welding Services Inc. (WSI) and Structural Integrity Associates Inc. (SI). This 25-year partnership started with weld overlay repair of BWR primary system welds due to IGSCC damage. In recent years, this team has set the industry standard for the engineering, licensing, implementation, and inspection of Alloy 600 component repairs.

STRUCTURAL INTEGRITY UNIVERSITY

By HAL GUSTIN

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Structural Integrity Associates, Inc. (SI) has always included technical training as one aspect of the support we provide to our clients. We offer several intensive short courses to our clients, typically of one-three days in length. These have been offered at client sites, local meeting facilities, and SI offices in the past, and the schedule for each course has been independent of the other courses.

During three weeks in June, SI collected the majority of our training offerings and offered them as a group, near our office in Huntersville North Carolina. We called this combined offering (somewhat tongue in cheek) “SI University”. It gave our clients the opportunity to attend several of our classes at the same location.

The last of the classes in the sequence offered was SI’s Metal Fatigue and Fracture Mechanics in the Nuclear Industry, taught by myself and Dilip Dedhia. There were attendees at this course from several US nuclear plants and utilities, as well as participants from Switzerland and Belgium. Participants from the USNRC, a local university and a gas pipeline engineer from a local utility also joined in the class. Because of the diversity of the class members, discussion was very wide-ranging and drew on the crack-related experience of everyone.

We provided class members with demonstration versions of SI’s pc-CRACK and Win Praise software, and they experimented with our software to solve problems in class. This “lab session” format was a new addition to the Metal Fatigue and Fracture Mechanics content compared to previous offerings of this course, and it was very well received.

Judging by the comments received on the various course evaluation questionnaires, attendees at all of the SI University classes very much enjoyed their experience, and found this training to be quite valuable. Such classes have also met the need for continuing education credit for attendees who have to fulfill such requirements as part of renewal of Professional Engineer licenses.

If you’re interested in additional training for you or your company, go to

http://www.structint.com/resources/training

or contact 877-4SI-POWER or info@structint.com.

All Structural Integrity Associates, Inc. (SI) courses can be conducted at the client’s site or at one of SI’s offices.
Rotating components on steam driven turbines and generators, inclusive of the rotor shafts, turbine disks, couplings, generator retaining rings, and turbine blades, are massive and rotate at high speed. Catastrophic failure of any of these rotor components can produce extreme consequences in terms of the damage to the turbine or generator itself, as well as collateral damage throughout the T/G set and, in the event of missile generation, to other systems and components in the plant. And there is the even more significant risk to the safety and well being of the plant personnel.

And these components do fail occasionally. As a direct result, each undergoes periodic inspection to detect conditions that could negatively impact its capacity to support additional service for a specified reinspection interval without assuming undue risk of failure. But inspection is only a part of the process. Most operative damage mechanisms that impact these major components are relatively slow growing – low cycle fatigue associated with number of starts and stress corrosion cracking are the most prevalent. And where rapid growth is possible under certain operative conditions, for example certain generator rotor retaining rings operating in a moist environment, these conditions are not prevalent when appropriate moisture mitigation programs are implemented. These factors provide an opportunity to manage the assets to extract as much usable life as possible. Stress and fracture analyses can be performed using established material properties, known damage progression rates, nondestructive evaluation findings, and the operative stress at each detected discontinuity to assess remaining life, and run/repair/replace decisions can then be made based on the results.

DETERMINISTIC ANALYSIS

Deterministic analysis is one in which a single value for each of the input variables used in the remaining life calculation is set to a single value and the remaining life is calculated on this basis. This calculation typically results in an extremely conservative result because a worst case value is typically used for each variable. Consider the simple example that includes only three variables: current flaw size, fracture toughness, and crack growth rate. For the sake of simplicity, further assume that the fracture toughness variability results in a critical flaw size range of 0.5-inch to 0.75-inch depth. For the remaining variables, the current flaw size is 0.1-inch to 0.2-inch deep, and crack growth rate ranges between $1 \times 10^{-5}$ to $5 \times 10^{-5}$ inch per hour. Using the conservative approach, the calculation would then be made using the fastest growth rate of $5 \times 10^{-5}$ inch per hour, the largest possible flaw size of 0.2-inch, and the smallest possible critical flaw size of 0.5-inch, resulting in a calculated remaining life of 6000 hours, or eight months. However, if the best case variables are used, the calculated life is 65,000 hours, or over 7 years. For the most conservative assessment, it would be very difficult to return the component to service, even if only for a short period, leaving the owner/operator no time to plan and implement repair/replace options.

While this example calculation is very simplistic and by no means representative of an real case, it does show the extreme disparity, over an order of magnitude, that can ensue with only three variables, each having relatively tight ranges. In the real situation, there are more variables, typically having even more extreme ranges. In addition, this approach accounts only for the ranges as they are defined, likely by experience, and does not account for the very real possibility that the “known” ranges may not fully represent all possibilities. In reality, the disparity between the worst case and best case calculations can easily be two or three orders of magnitude.

So, how do we deal with this disparity? First, we know that either extreme is very unlikely to occur. These would require that either all worst case variables or all best case variables occur in the same component, at the same location, at the same time. In reality, the actual value for each variable is most likely somewhere between and if normally distributed, then at the mid-range value. So, is the answer to calculate the remaining life using the mid-range value for each variable? Actually, the probability of any single solution being the correct solution is extremely low,
which is why the argument is typically made to err on the conservative side using the worst case solution. But we can do better, and the answer is in the probabilistic analysis.

PROBABILISTIC ANALYSIS
Under a probabilistic approach, all input parameters are quantified as statistical distributions rather than single point values, accounting in the process not only for the known ranges but also for the possibility of broader distributions. A Monte Carlo simulation is exercised to determine the probability of failure in a specified operational interval. In the Monte Carlo simulation, a value is picked from the distribution for each of the input variables. In this assessment, however, rather than calculating the life based on the selected values, a remaining life is specified and the calculation determines if the component would fail or not in this lifetime given the selected values. The process is repeated over and over, each time selecting a new set of values based on the distributions. For a variable that is normally distributed, statistics tell us that the value will be within +/- one standard deviation of the mean value 67% of the time, within two standard deviations of the mean 95% of the time, and within +/- three standard deviations 99% of the time. So, the values selected for the calculations are clustered around the median value of the distribution, and only occasionally will the extreme values be selected. The process continues, allowing the computer to select values and make the calculation many thousands of times and keeping track of the number of failures and the number of non-failures. The number of failures divided by the number of calculations is the probability of failure for the defined operational life. This same process is then repeated using different remaining life values, with the final output expressed via a curve that presents cumulative probability of failure versus time. To take advantage of the lowered conservatism, however, the owner must be willing to deal with the output in the form of a probability of failure in a specified operational life. The owner must decide the probability of failure that represents an acceptable risk.

WHAT’S ACCEPTABLE RISK?
Typically, operators consider a 0.1% probability of failure over the intended operational period until the next scheduled inspection to be acceptable. For Nuclear units the acceptable risk is more typically 0.01% (1 in 10,000). But the comfort level is something that only the owner/operator can define based on their tolerance for risk. In reality, there is risk associated with operation of a unit regardless the assessment that is conducted. The probabilistic approach merely quantifies this risk.

INDEPENDENT PROBABILISTIC LIFE ASSESSMENT CODES
The Electric Power Research Institute (EPRI) recognized the limitations of deterministic assessment and the fact that these assessments were leading to many component retirements, many of which were likely unnecessary. And for these components, replacement costs are not at all trivial. To boot, utilities were being pushed in many cases to unplanned, unscheduled outages while awaiting replacement components, additionally at great cost. EPRI has now sponsored the development of three independent probabilistic life assessment codes. SAFER (Stress And Fracture Evaluation of Rotors) looks at the rotor forging, concentrating on the near bore material, and additionally can be used to evaluate turbine disks. This program provides probabilistic treatment of the standard variables, i.e., flaw size, fracture toughness, fracture appearance transition temperature (FATT), low cycle fatigue crack growth rate, etc. RRing-Life is used for generator retaining rings, which is a case in which growth rate under certain environmental conditions can be rapid, but the likelihood of experiencing these conditions can be slight and certainly extremely variable. In this program, even though material properties and other typical variables are treated probabilistically, the primary emphasis is on the probabilities to hostile environments. LPRimLife is used to assess stress corrosion cracking in low pressure rotor disk rim blade attachment dovetails. In this case, emphasis is on the growth rate change as the crack grows and stress is redistributed to other than the cracked hook(s) on the fir tree attachment.

SI ADVANTAGE
Structural Integrity Associates, Inc., (SI) has participated in all three of these developments, having been the development contractor for LPRimLife and RRing-Life and having worked extensively with EPRI on upgrades, training and support of all three. We hold EPRI licenses for commercial implementation of the three programs and have significant experience in their use. We couple these programs with our state of the art inspection services, rotor machining services, miniature sampling capabilities, and full service materials testing laboratory to provide the most comprehensive rotor component lifting services available in the industry.
Materials Selection for New Plant Designs

As orders for new plants are beginning in the U.S., Structural Integrity Associates, Inc., (SI) is working with one vendor to provide technical support on materials selection and certification for main steam line piping to apply the leak-before-break (LBB) approach. LBB design relies on a materials’ resistance to elastic-plastic fracture to assure that a reactor can be shutdown safely by detection of leakage before a pipe break could occur. There are many benefits for using LBB for new plants, such as: elimination of a double-ended guillotine break as a design consideration, and elimination of the need for pipe whip restraints, jet impingement barriers and flow injection prevention walls. This improves access for in-service inspections and significantly reduces radiation exposure to workers throughout the life of the plant.

Using LBB in the design stage greatly simplifies the design process and can result in savings of many tens of millions of dollars in plant design and construction costs.

The tradeoff is that the materials of choice must meet the requirements in NUREG-1061, Vol. 3, “Evaluation of Potential for Pipe Breaks” based on the material tensile strength and J-R fracture resistance (fracture toughness).

The challenge is to choose piping materials that have both sufficient strength and toughness to meet these requirements. Plus, there are other factors that must that must be considered such as weldability and related material properties at the weld locations. Fabrication of seamless pipe may eliminate some welds in the piping runs, but it complicates the material selection process because seamless pipe in the thickness and diameter of the main steam line is much more difficult to fabricate. The material specifications must be tightened and process controls implemented to assure that the piping system properties are achieved per the LBB requirements. This must be demonstrated by a materials testing program to prove that the material specifications and ultimate material properties meet or exceed design requirements. In order to achieve the design certification, the NRC must approve the approach.

FIRST-OF-A-KIND ENGINEERING

SI assembled a team of analysts and materials experts to work closely with the NSSS vendor, perform the LBB analyses and identify potential piping material suppliers, welding specialists and material testing laboratories who can deliver nuclear grade piping materials and services under a nuclear QA program. In addition, we provide the project management and QA administrative functions throughout the project, a key element of making this effort a success. The range of skills needed to perform these tasks shows that we have the broader capabilities to take on a bigger role that may have been traditionally performed by the reactor vendor and the Architect Engineer. This project also demonstrates the complex nature of material selection and procurement for the next generation of plants, and that we can function in this role and deliver a product that will be first-of-a-kind engineering for this particular application.

Continued on next page
We are working toward milestones later this year to show that the material selection and design process works. This project is now underway with the cooperation and participation of several other organizations, including Energy Steel in Lapeer, MI and Westmoreland Testing Laboratories in Pittsburgh, PA. Key decisions will soon be made regarding improved materials specifications, and a prototype sampling of the piping and weld materials will be ordered for the demonstration phase of the project. This next phase will show that the materials of choice can meet the stringent design requirements. For example, higher than Code minimum tensile and yield strength must be achieved for the class of carbon steel materials being considered (e.g., SA333 Gr. 6 or SA106 Gr. B) that can be heat treated (i.e., quenched and tempered) to increase their strength. However, increasing the strength may also decrease the toughness and ductility, so additional measures must be employed to assure that the fracture toughness, as measured by the J-R curve, also exceeds the design requirements. Improvements in toughness are a combination of factors considered to be good foundry practices, including strict chemical controls of the ingot, minimization of inclusions, and process controls throughout the forming and heat treating of the piping. The controls on foundry practices lead to fine grain microstructure, as shown in Figure 1, with corresponding excellent strength and ductility.

Figure 1: Typical microstructure of SA333 Gr. 6 pipes. (a) x 100 and (b) x 200.
The project involves selection of the proper combination of base materials, filler materials, welding process and techniques aimed to provide a repeatable welding schedule which will be controlled via a prescriptive welding procedure. A series of mockups and weld tests will be required to achieve such goal, and extensive weld tests will be performed to generate data in support of the final welding procedure.

**THE PREFERRED WELDING PROCESS**

Achieving high quality welds may require use of Gas Tungsten Arc Welds (GTAW) with weld demonstrations and weld procedure qualifications that will also assure the high strength and toughness in these welds. GTAW is the preferred welding process for joining the pipe since it produces the best combination of mechanical properties in the weld deposit and the Heat Affected Zone (HAZ). The arrangement of a machine GTAW system is shown in Figure 2. Although conventional flux processes such as Shielded Metal Arc Welding (SMAW) or Flux Cored Arc Welding (FCAW) can provide a higher rate of deposition, these welding techniques pose a challenge in meeting the stringent mechanical properties prescribed for this application.

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**OUR SI TEAM**

This project was addressed by a team of our experienced SI experts who were involved in the design and selection of materials for the existing fleet of nuclear plants and complimented by skilled engineers and metallurgists who are learning from our experts. We’re ready to take on even bigger challenges for the next generation of plants.

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**Figure 2:** A machine GTAW system can be used for welding on the large diameter MSL pipe

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Collectively, Structural Integrity Associates, Inc., (SI) has a lot of useful knowledge, but what about the useless? Impress your coworkers by sending us your most trivial, entertaining science and engineering knowledge for the next edition of Cool Facts to info@structint.com.

The Sliding Rocks of Racetrack Playa, Death Valley, CA

Racetrack Playa is a dry lake bed in Death Valley National Park. Rocks as small as a few inches in diameter up to ones weighing 700 lb slide across the lake bed floor in seemingly random directions. The lake bed does not show any signs of human or animal activity, so the most common theory is that they are moved through the mud by wind and ice during the winter. During one study, a small rock moved over 650 feet in one winter, while a 700 lb rock disappeared. The sliding has never been observed, so the exact cause of the motion is still unknown.

Photo from http://geology.com/articles/racetrack-playa-sliding-rocks.shtml
The Fossil FAC International Conference held June 29-July 1, 2010 marked the first international gathering of scientists and engineers at a meeting focused on the subject of FAC in fossil and combined cycle steam and power systems. Five organizations were involved with the conference:

- CEATI (Centre for Energy Advancement through Technological Innovation) International (Canada)
- Combined Cycle Journal
- Electric Power Research Institute (EPRI)
- PowerPlant Chemistry Journal
- Structural Integrity Associates, Inc. (SI)

Barry Dooley (Conference Chairman), Kevin Shields (Conference Co-Chairman) and Steve Shulder of SI organized the conference, assembled the technical program and arranged the exhibition.

The organizers worked with an International Advisory Group of 20 FAC specialists from around the world. In all there were 177 registered attendees from 21 countries. The technical program consisted of 40 papers presented by researchers, plant operators and service organizations.

By design the meeting was linked with FAC2010, organized by Électricité de France (EDF), a conference focusing on FAC in nuclear power stations, held in May, 2010 in Lyon, France. Common attendees of the two conferences helped to connect the knowledge from the fossil and nuclear areas.

**CONFERENCE PROGRAM**

The conference included 13 technical sessions. A Plenary Session consisting of three papers set the tone for the conference in terms of knowledge, uncertainties and discussion topics:

- “Although Understood, FAC Remains an Enigma”, B. Dooley, Structural Integrity Associates (United States)
- “Reflections on FAC Mechanisms”, D. Lister, University of New Brunswick (Canada) and S. Uchida, Institute of Applied Energy (Japan)
- “The NDE Options for FAC”, S. Walker, Electric Power Research Institute (United States)

Other session themes included FAC Mechanisms, FAC Predictive Codes and Models, Flow Modeling, End User FAC Programs, Nondestructive Examination Methods and Material Analysis, FAC in Combined Cycle Plants with Heat Recovery Steam Generators (HRSG), Cycle Chemistry Influences on FAC, FAC in Air-cooled Condensers (ACC), and Plant FAC Experience Reports (covered in four sessions).
TECHNICAL HIGHLIGHTS

Conference presentations touched on all important aspects of FAC in fossil steam and power generation systems. A number of important findings and key messages were communicated by presenters and covered further during question and discussion periods. These include the following:

FAC in the Fossil Industry: Damage and failures of carbon steel components due to FAC are possible in all fossil systems operated in the temperature range of about 50-250°C (~120-480°F). ACCs operating at temperatures as low as 30°C (~90°F) have experienced low temperature two-phase FAC. A recent evaluation has suggested that similar damage occurs in two-phase regions of water-cooled condensers.

FAC Mechanisms: FAC occurs in both single-phase and two-phase areas. Key chemistry parameters influencing FAC include electrochemical potential, dissolved oxygen and pH. Geometric factors affect local turbulence resulting in increased damage relative to areas with low turbulence. Factors controlling the rate of damage appear to be pH dependent with mass transfer being the controlling factor at neutral pH and kinetics being more important at elevated pH. While FAC is known to involve dissolution of iron oxides into the water phase, analysis of samples from plants indicate that about 90% of the iron on a mass basis is present as particulate material. This aspect deserves further investigation. Another mechanism, liquid droplet impingement (LDI), has been suggested as possibly responsible for some damage in two-phase areas with very high flow velocities. However, further work is needed to further distinguish and verify proposed differences between LDI and two-phase FAC.

FAC Predictive Codes and Models: Three predictive codes developed for FAC evaluation and prediction in nuclear plants are not completely applicable to fossil applications. An important limitation has been the nearly total focus on reducing chemistry, which must be used in nuclear systems. Work is now in progress to include the oxidizing regimes which can be used in some fossil and most combined cycle/HRSG systems. Experience in modeling of conventional fossil systems and combined cycles is limited and further work is needed to refine and verify the predictive capabilities. CFD or flow modeling is a relatively new area of investigation for FAC which offers promise with respect to identification of geometries most likely to be subject to severe FAC damage. At present, development is focused on single-phase conditions with plans to ultimately consider two-phase conditions.

FAC Inspection Technology: A number of inspection techniques are available and applicable to identification of FAC. Each has unique attributes and limitations that define conditions under which the technique can effectively be used. For comprehensive plant inspections, use of multiple inspection methods is needed. Inspection methods developed for conventional fossil systems often have limited applicability to HRSGs. Development activity is needed to produce techniques which can be applied from the inside of tubes and headers.

End User FAC Programs and Experiences: Interest in FAC avoidance has resulted in increased attention from end users. Most have enacted FAC programs and done some inspection work. However, there are still a number of misunderstandings about FAC that are apparent based on review of plant practices to control and identify locations with FAC. In general, fossil end users demonstrate a better understanding of single-phase FAC than two-phase FAC.
FAC EXPERTS PANEL AND ROUNDTABLE DISCUSSION, JULY 2, 2010

Following the conference an open discussion of FAC topics was convened. Seven conference attendees with expertise in various aspects of FAC made opening remarks presenting their assessment of the formal presentations. About 50 attendees participated in the discussion. Important discussion points included the following:

- The best FAC Programs are supported by management and clearly define policy, roles, responsibilities and resources.
- Communication and clearly defined specifications are essential to FAC resistant designs and when inspecting components for FAC damage.
- FAC rates are variable and dependent on many factors. A conservative approach must be taken when considering repair/replacement of damaged components.
- In-kind replacement of damaged components will lead to additional FAC; modified geometries can increase the damage rate. Use of steel containing 0.1% or greater chromium eliminates FAC susceptibility.
- Alternate chemistry control practices should be considered for control of two-phase FAC. Approaches mentioned included use of neutralizing amines, possibly blended with ammonia for pH control, and filming amines.
- In units with oxidizing chemistry, closure of deaerator and feedwater heater vents can reduce two-phase FAC damage. Many plants that could operate with the vents closed do not.
- Use of robotics technology appears to offer the greatest possibility of improved inspection of HRSGs. Robotics technology is available and used in (non-FAC?) nuclear applications.
- Alloy analyzers are less commonly used in fossil plants than they are in nuclear plants.
- Iron monitoring, while generally accepted as a means of evaluating FAC control, is subject to a number of sampling and analysis concerns. Use of particle monitors to provide an indirect indication of corrosion product transport is now being evaluated in a number of plants, including some with ACCs.
- End users indicate additional FAC awareness and training is needed in many cases.

Discussions were robust and continued until the end of the time allocated. It was the consensus of the group that, although there is an excellent technical understanding of FAC in fossil and combined cycle plants with HRSGs, there continue to be unusual and unexpected observations in working plants. Additional research is needed to explain these observations and improve and expand FAC prediction and inspection capabilities. Also, continued transfer of FAC technical knowledge to end users is needed.

CONCLUSION AND FUTURE PLANS

The conference was timely in that it was held at a time when many organizations are placing increased emphasis on FAC. The technical program and attendee perspectives resulted in clarification of many questions related to FAC while also identifying aspects requiring additional attention.

A number of conference papers will be published in Power Plant Chemistry and Combined Cycle Journal. Arrangements to publish the complete proceedings are under development.

Attendee and exhibitor feedback was very positive and included several suggestions that arrangement of future conferences would be of benefit to industry. Based on the attendee feedback, the Second International Conference is tentatively planned for June 2012 at an undetermined North American location with linkage to the EDF 2012FAC meeting which will be held in Lyon France. A formal announcement of dates and venue is planned for early 2011.
Dynamic Stability Analysis
of Spent Fuel Transfer System

When it comes to earthquake response, sliding a short distance is more desirable than tipping over. Structural Integrity Associates, Inc. (SI) recently completed a stability analysis of a dry fuel transfer system for one of our nuclear power plant clients. Transferring spent fuel into the plant’s dry fuel storage system involves a step in which the spent fuel canister is lowered from a transfer cask into the storage module while the system is freestanding on a transportation dolly in the Reactor Building. As an alternative to physical restraints, the freestanding cask transfer system makes use of a special sliding pad that rests on top of the dolly platform, which functions like a base isolation system in the event of an earthquake.

The premise of the stability analysis was to demonstrate that the fuel transfer system in its stacked configuration. However, the NRC questioned various aspects of the kinematics analysis, including whether the kinematics program had been previously accepted for such analyses by the NRC. In responding to the NRC’s questions, the plant decided that a 10 CFR 50.59 evaluation should be conducted to determine if the stability calculation could be accepted into the plant’s licensing basis without NRC approval.

Our client contacted us to provide supporting calculations and documentation for the 10 CFR 50.59 review and to perform an independent stability evaluation using an analysis method fully vetted by the NRC. We reviewed NRC-accepted methodologies and computer codes for stability analyses of dry spent fuel storage components and concluded that an analysis using LS-DYNA could be applied to the stack-up. LS-DYNA is regularly used for the dynamic analysis of dry fuel storage system drop and impact loads and has been used to determine the sliding and rocking response of the storage module of another licensed spent fuel storage system.

Both SI calculations used a rigid body dynamics approach in LS-DYNA, with loading consisting of safe shutdown earthquake (SSE) acceleration time history curves artificially generated from floor response spectra. Model views are shown in Figures 1 and 2. Sample time history traces are shown in Figure 3.

For the independent stability analysis, we performed multiple rigid body dynamics simulations using three different sets of artificial seismic floor excitations. Floor motion was imposed using prescribed time-varying acceleration time histories in the three orthogonal spatial directions (NS, EW and vertical). The resulting displacements, energies and reaction forces were evaluated to determine factors of safety against tipping and sliding off the dolly platform.

When we applied a lower bound friction coefficient, sliding increased, but the stack-up did not tip as much, and the kinetic energy response of the system was reduced.
We found the stack-up to be sufficiently stable, and the factors of safety we computed for the critical load cases were similar to the factors of safety computed by the system vendor in the previous stability calculation. Acceptance criteria for sliding and overturning of this system are provided in NUREG-1536 (Dry Fuel Storage Systems) and NUREG-0800 (Light Water Reactors). Compared to the acceptance criteria, the system exhibits significant margins of safety, particularly when the sliding pad promotes sliding rather than tipping.

**Figure 3.** Sample earthquake time-history curves generated for the stack-up stability analysis.
The new NEI 09-14, *Guideline for the Management of Buried Piping Integrity*, has established metrics for the data collection, risk ranking, inspection and corrosion management of buried piping at nuclear plants across the US.

Addressing Buried Pipe program needs has taken a huge step forward this year with the latest EPRI BPWorks™ 2.0 database and risk ranking software. The new database and software, scheduled for industry release in October 2010, provides a centralized location for the storage of buried pipe design, operating, corrosion control, historical and all types of monitoring and inspection data – including: GWT, Cathodic Protection (CP), and UT.

Structural Integrity developed the new nuclear industry data model that serves as the foundation of BPWorks 2.0 under EPRI funded project EP-P33391, “Collaboration to Enhance BPWorks”. The project scope was to create a database structure and user interface application to allow for the manipulation of all required data described in EPRI report 1016456, *Recommendations for an Effective Program to Control the Degradation of Buried Pipe*. The project met this requirement and surpassed it by also including the ability to store significantly more detailed information than is required for only performing the BPWorks risk analysis. These robust enhancements will allow this data model to become a one-stop engineering resource tool for buried pipe engineers. Documents and photos can be linked to the data, detailed inspection values can be stored, and multi-user access is possible, to name only a few of robust qualities of this new tool.
To compliment BPWorks 2.0, Structural Integrity Associates, Inc. (SI) has also enhanced MAPPro. We have developed specialty applications for:

- **MAPProRisk™**: this permits the assessment of non-steel, non-water systems and leverages both CP and inspection results in the final risk assessment.
- **MAPProView™**: our unique way to visualize in 2D or 3D the location of all buried assets with links to information in the database.
- **MAPTank™**: for the management and risk ranking of buried and above ground tanks, sumps, and vessels.
- **GWT**: for the viewing of GWT data. Includes the importing of results and alignment of features into MAPProView.
- **Well Data**: for the management of tritium monitoring wells.
- **And various other data management tools.**

We will be announcing the formation of a MAPPro user group in 2011 to further enhance these applications and provide more tools that either streamline the data handling process or automate other engineering calculations. Tools are currently underway for automating code case N-513-2 calculations, trending CP and other monitoring data, and inspection method selection and planning.

**THE NEXT NEI 09-14 DEADLINE**

To meet the next NEI 09-14 deadline for completion of the risk analysis of all buried piping systems, SI is currently underway, or has recently completed, database population projects for the STARS group (Callaway, Comanche Peak, Diablo Canyon, Palo Verde, South Texas Project, SONGS, and Wolf Creek), Constellation, Entergy, and multiple other sites. About 1/3rd of US nuclear sites are using our MAPPro applications in conjunction the new BPWorks 2.0 software. Tools have also been developed to help BPWorks™ 1 and BPManager™ users upgrade to the new BPWorks 2.0 software. Additional tools are available that will recombine older “forced segmentation” data sets to be able to leverage the new dynamic segmentation functionality integrate data to reveal areas along a pipe with unique sets of conditions indicative of a higher risk potential.

Several APEC (Area Potential Earth Current) survey results were validated at nuclear sites in 2010 through excavations. These results are confirming that APEC surveys can evaluate the effectiveness of aging external pipe coatings and assess the performance of cathodic protection locally around the site. For more information about APEC see our website, www.structint.com/NewsandViews.com or the Spring 2010 edition of News & Views.

If you would like to learn more about how Structural Integrity Associates can help your organization meet its buried piping needs, Contact us today at 877-474-7693 or visit us at: www.structint.com/Management-of-Aging-Buried-Piping
UPCOMING EVENTS

ASME B&PV Code Week
Vancouver, BC November 1-4, 2010

SI WEBINAR: Current Status of Risk Based Programs
Scott Chesworth November 8, 2010 2:00pm

2010 API Fall Refining & Equipment Standards Meeting
Nashville, TN November 15-17, 2010

2nd International Conference & Exhibition on Instrumentation for Power Plant Chemistry
Stuttgart, Germany November 15-17, 2010

SI WEBINAR: License Renewal / Fatigue / TLAA
Dave Gerber / Tim Griesbach December 8, 2010 2:00pm

SI WEBINAR: HDPE - Materials, Design, Analysis and Examination
Caleb Frederick January 13, 2011 2:00pm

Power Gen/NucPower
Orlando, FL December 14-16, 2010 2:00pm

Energy Generation Conference
Bismarck, ND January 25-27, 2011 2:00pm

ASME B&PV Code Week

EPRI Buried Pipe Information Group (BPIG) Meeting
Palm Coast, FL February 14, 2011

SI WEBINAR: HDPE - Dynamic Analysis / LS-DYNA
Shari Day February 17, 2011 2:00pm

SI WEBINAR: HDPE -
Dynamic Analysis / LS-DYNA
Shari Day February 17, 2011 2:00pm

NACE Corrosion 2011 Conference
Houston, TX March 13-17, 2011 - February

For more information on these events and Structural Integrity, go to:
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