# The Proactive Management of Materials Degradation (PMMD) and Enhanced Structural Reliability

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## 1 ABSTRACT

One of the goals ascribed to the proactive management of materials degradation is to enhance structural reliability through the management of in-service degradation of metallic components in aging nuclear power plants (NPPs). As life extension of these plants is considered, some forms of degradation, such as stress corrosion cracking (SCC), will be of increasing concern as they are characterized by a long initiation time followed by a rapid growth phase. New nondestructive evaluation (NDE) techniques may be needed to find degradation precursors to the SCC initiation, and to provide on-line monitoring techniques to detect cracks as they initiate and grow.

This paper discusses the U.S. Nuclear Regulatory Commission's (NRC) activities to further the Proactive Management of Materials Degradation (PMMD), including those to determine the effectiveness of emerging NDE techniques. The paper discusses the first part of the development of a methodology to determine the effectiveness of these emerging NDE techniques for managing metallic degradation. This methodology draws on experience derived from evaluating techniques that have 'emerged' in the past. The methodology will follow five stages: a definition of inspection parameters, a technical evaluation, laboratory testing, round-robin testing, and the design of a performance demonstration program. This methodology will document the path taken for previous techniques and set a standardized course for future NDE techniques.

## 1 INTRODUCTION

There are 436 operating nuclear power reactors in the current global fleet, with an additional 44 reported as under construction and 110 planned; 104 of the operating reactors are in the United States. The average age for these facilities is more than 20 years; however, the design lives were in the range of 30–40 years. In a number of countries, there are programs that are looking to enable operating life extension from 40 to 60 years, and some consideration is being given to "life beyond 60."

The U.S. nuclear industry has expressed interest in "life beyond 60"; that is, plants applying for a second renewal period to continue operation in the 60- to 80-year license period. U.S. regulations allow for additional renewals provided that, as in the case of the initial renewal period, the licensee continues to demonstrate compliance with NRC regulations during the extended operating period. Research and regulatory process reviews are being conducted for the second, and subsequent, license renewal periods.

Nuclear power provides carbon-free base load generating capacity, and particularly in the current economic situation the existing nuclear power plants are too valuable to decommission at the end of their current license period (WNA 2009). The cost of building replacement generating capacity, and at the same time providing new plants that meet the growth in demand for electricity, would test both the available manufacturing and economic infrastructures. It is therefore important to see where technology can help to better manage existing power plants, enable life extension for the existing fleet, and contribute to both new advanced light water reactors and new designs, with demanding materials and operational requirements.

In support of NPP license renewal over the past decade, various national and international programs have been initiated (Bond et al. 2008a). The NRC has undertaken a program to lay the technical foundation for defining proactive actions so that future degradation of materials in light water reactors (LWRs) is limited and, thereby, does not diminish either the integrity of important LWR components or the safety of operating plants. Currently, U.S. licensees are requesting license extension periods of an additional 20 years on many of their plants, and consideration is now being given to the concept of "life-beyond-60"; that is, a subsequent license extension covering the operating period from 60 to 80 years. There is also planning underway for potentially longer operating lives.

Based on the Atomic Energy Act of 1954, as amended (Public Law 83-703), the NRC issues initial operating licenses for commercial nuclear power reactors for 40 years (based on economic and antitrust considerations, not technical limitations). Further, these licenses can be renewed in 20-year increments provided that the licensee can demonstrate that they can continue to safely operate the plant in accordance with the requirements enumerated in Parts 51 and 54 to Title 10 of the *Code of Federal Regulations* (10 CFR Parts 51 and 54). However, once the license term was selected, aspects of individual plant designs were engineered on the basis of an expected 40-year service life, and therefore need to be reviewed to consider aging management effects when considering renewal of the license. As such, the NRC has established a license renewal process that can be completed in a reasonable period of time with clear requirements to assure safe nuclear plant operation for periods beyond the original license period. License renewal is voluntary and the decision whether to seek license renewal rests entirely with nuclear power plant owners. This decision is typically based on the plant's economic situation and whether it can continue to meet NRC requirements. As of April 2009, 51 of the 104 licensed, operating commercial NPP reactors in the United States have received a renewed license, authorizing continued operation up to 60 years.

The NRC's license renewal review focuses on the effectiveness of managing aging effects for passive, long-lived components. Existing programs, such as the maintenance rule and performance and condition monitoring programs, provide an effective means to monitor active equipment reliability. Thus, license renewal focuses on passive components where aging effects on functionality are typically revealed over longer time periods. Short-lived components are replaced as part of routine maintenance. NRC documents its review in published safety evaluation and environmental impact reports, and performs license renewal inspections—team inspections to sample the process used by the utility to identify the systems, structures, and components (SSCs) requiring review and an aging management inspection to verify that aging management plans, which monitor the age-related degradation of the passive SSCs, are being properly implemented. The licensee's renewal application and the NRC's safety evaluation are reviewed by the independent Advisory Committee on Reactor Safeguards (ACRS), which provides a recommendation to the Commission on renewing the license. Further, an opportunity is provided for members of the public to petition for a formal hearing to address specific issues related to plant safety or environmental impacts. If a hearing is conducted, the outcome is provided to the Commission for its consideration in making a decision on renewing the license.

All parts of an NPP are subject to the continuous time-dependent degradation of materials due to normal service conditions, which include normal operation and transient conditions. The PMMD program is investigating the many materials and components in NPPs, and the materials degradation phenomena that affect them, in an attempt to predict and thus mitigate or prevent future problems. As some forms of degradation, such as stress corrosion cracking, are characterized by a long initiation time followed by a rapid growth phase, new inspection or monitoring technologies may be required. New NDE techniques that may be needed include techniques to find SCC precursors, on-line monitoring techniques to detect cracks as they initiate and grow, and improved current NDE technologies. As the reactors operate well beyond their originally licensed and planned lifetimes, many reactor components may need to have their present NDE programs augmented in order to prevent failures because the NDE programs were originally intended for only 40 years of operation.

The need for new NDE technologies and techniques necessitates developing a methodology for the evaluation of these approaches to determine, in a timely fashion, if they have a strong technical basis. Previous efforts in evaluating NDE technologies and techniques have lacked a structured methodology and have been very time-consuming. The methodology discussed below, which is based on previous evaluations of NDE technologies, consists of four distinct phases. The first phase is an expert review of the physics of the new technique and the applicability of the technique to the affected components. The second phase is a series of laboratory tests to determine the effectiveness of the technique under laboratory conditions and to explore the essential variables. In the third phase, after the laboratory testing, a round-robin test would be conducted using commercial vendors to determine if the field-deployed systems can operate effectively under realistic conditions. The final phase would be the implementation of performance-based testing to assure that the inspectors, technology, and technique are all able to provide an adequate probability of detection (POD) for measurements on degradation in NPP components.

Additionally, a comprehensive review of reactor components will be needed to determine if new inspection regimes may be required to deal with new degradation mechanisms that may emerge over time. As reactors lifetimes are expanded, degradation mechanisms previously considered too long-term to be of consequence (such as concrete and wiring insulation degradation) may become significant.

## 2 IMPROVED ECONOMICS OF NUCLEAR PLANT LIFE MANAGEMENT

The adoption of new on-line monitoring, diagnostics, and eventually prognostics technologies has already been shown to have the potential to impact the economics of the existing NPP fleet, new plants, and future advanced designs. The economic benefit from a predictive maintenance program based on advanced on-line monitoring and advanced diagnostics can be demonstrated from a cost/benefit analysis. An analysis of the 104 U.S. LWRs has indicated potential savings at over $1B per year when applied to all key equipment (Bond et al. 2007). To move from periodic inspection to on-line monitoring for condition-based maintenance and eventually prognostics will require:

- advances in sensors;
- better understanding of what and how to measure within the plant;
- enhanced data interrogation, communication and integration;
- new predictive models for damage/aging evolution;
- system integration for real-world deployments;
- quantification of uncertainties in what are inherently ill-posed problems; and
- integration of enhanced condition-based maintenance/prognostics philosophies into new plant designs, operation, and operations and management (O&M) approaches.

The move to digital systems in petrochemical process and fossil fuel power plants is enabling major advances to occur in the instrumentation, controls and monitoring systems, and approaches employed (ANS 2009). There are significant opportunities to adopt condition-based maintenance when upgrades are implemented at existing facilities (Bond et al. 2007). The adoption within the nuclear power community of advanced on-line monitoring and advanced diagnostics has the potential for:

- reduction in costly periodic surveillance that requires plant shut-down;
- more accurate cost-benefit analysis;
- “just-in-time” maintenance and pre-staging of maintenance tasks;
- movement towards true “operation without failures”; and
- jump start on advanced technologies for new plant concepts, such as those proposed under the International Generation IV (GIF) Program.

## 3 PROACTIVE MANAGEMENT OF MATERIAL DEGRADATION (PMMD)

One of the objectives for PMMD is to identify materials and components where future degradation may occur. In some cases, the degradation may involve phenomena not yet experienced in the operating fleet but where there is laboratory data and/or a mechanistic understanding that indicates that they may be pertinent to future reactor operations.

PMMD includes the methodology and actions needed to manage both active and passive elements in the NPP systems throughout their existence to minimize the impact of degradation, maintain safety, and potentially enable extensions to system operating life (Bond et al. 2008b).

### **3.1** Relationship between PMMD and prognostics

PMMD is the emerging technical and methodological basis needed to support enhanced system management throughout its life, including life extension for existing (legacy) NPPs. These approaches involve “sensing” material property changes and parameter trends that are precursors to traditionally monitored degradation mechanisms and phenomena (e.g., crack growth) that are detected by conventional NDE/nondestructive testing (NDT) technologies such as eddy current or ultrasound. For PMMD to be effective, practitioners need to understand the phenomena of stressor-material interactions and sense early precursor material property changes. An example of a possible degradation phenomenon could be radiation-induced void swelling. PMMD also includes the assessment of the impact of material degradation on the system or unit life-cycle.

Prognostics can be defined as being a “forecast of future performance and/or condition.” Prognostics (for active and passive components) is the prediction of a remaining safe or service life based on an analysis of the system or materials condition, stressors, degradation phenomena, and operating conditions. In the context of materials degradation assessment, the concept of prognostics includes the science, enabling technology, and methodologies needed to predict the remaining safe (service or licensable) life and ensure operational reliability for a system. Prognostic methodologies can be implemented in several ways, but in all cases include degradation phenomena, the driving stressors, and (in most cases) models to predict the degradation rate and thereby extrapolate remaining life (or time by which intervention is required).

Such methods can therefore form a key element within a PMMD program by adding a “predictive” element to the proactive activities through the understanding and quantification of the rate of material degradation and resultant impact on system safety/life. Prognostic methods also provide a positive impact on probabilistic risk assessment (PRA) through the ability to manage and schedule outages and maintenance activities (Bond et al. 2007). The lexicon for the relationship between PMMD and prognostics is discussed elsewhere by Bond et al. (2008b).

### **3.2** Basic principles of proactive management of materials degradation

The difference between reactive and proactive approaches to the management of materials degradation is illustrated in Fig. 1. In the reactive management scenario, there is limited time following the initial degradation observation during which mitigation actions can be developed before an unacceptable degree of damage occurs. This constraint may lead to the deployment of incomplete ad hoc mitigation strategies. The time constraint is considerably reduced in the proactive management scenario, with the increase in available time for mitigation development being a function of the incubation time before damage starts and the subsequent kinetics of damage accumulation.

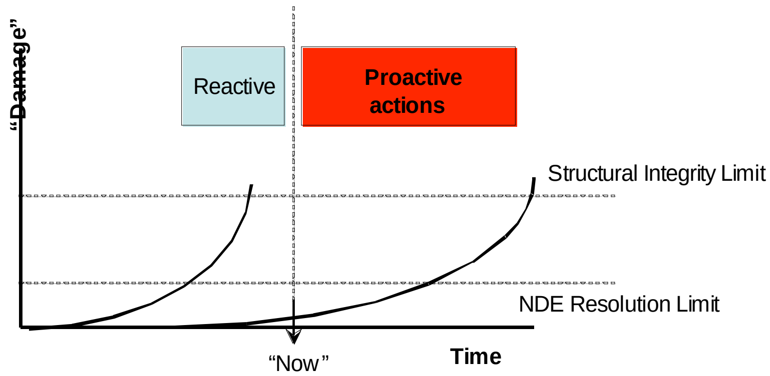


**Figure 1.** Schematic diagram illustrating degradation, or damage, development with time, and the differentiation between reactive and proactive actions. Note that the degradation process vs. time is rarely linear, as is often assumed.

In order to meet the objective of a proactive material degradation assessment and management program, it is necessary to understand stressors and assess various damage and damage accumulation rate/severity relationships for existing and potential degradation modes, materials, environments, and operating states for the different LWR components. This assessment may be based on formulations for the various stressor and damage-time relationships or more generally on the basis of operating and laboratory experience and engineering judgment.

The six principles of proactive management of materials degradation were deduced from Andresen et al. (2007) and are highlighted to emphasize their importance.

1) Materials degradation has occurred in LWRs and will continue as long as LWRs are in operation.[1] The trend within the nuclear power industry is to operate plants for longer periods of time and at increased

[1] LWRs are not unique in this aspect – all materials are subject to environmental and aging-related degradation.

power levels. The number of utilities requesting power uprates[2] and successfully applying for license renewal is an example of the trend. Materials degradation (especially potential new modes of degradation) will likely increase as NPPs are operated for longer periods of time and at increased power levels. The use of alternate materials or modified operating conditions may potentially counteract these factors but, in general, are not fully qualified and can address only a fraction of the degradation modes. The technical reasons for these statements are outlined in detail in NUREG/CR 6923 (Andresen et al. 2007).

2) The proactive management of materials degradation increases the available time for mitigation, which is a function of the incubation time before significant damage starts and the subsequent kinetics of accumulating damage.

3) In the consideration of power uprates and the potential for subsequent license renewal operating periods (e.g., "life beyond 60"), addressing degradation in a reactive fashion has the potential to result in an unacceptable loss of safety margin. Current reactive management of materials degradation limits the time window following the damage observation during which mitigation actions can be developed before an unacceptable degree or level of damage is reached. This constraint may lead to the deployment of incomplete mitigation strategies.

4) Extended operation of an NPP requires the plant owner to address two major issues concerning degradation.

   a. Developing effective aging management programs for known degradation as currently addressed in the NPP license renewal guidance documents (NRC 2005a, b).

   b. Developing a technically based program to understand the impact of stressors that can drive "damage" or material life utilization and then detect and mitigate both potential stressors and degradation that has not yet happened but has the potential to occur.

5) PMMD programs should include degradation mode-component combinations *with applied stressors* where there was a high susceptibility to degradation based in large part on multiple observations in operating plants regardless of the knowledge level concerning degradation.

6) PMMD programs should include degradation mode-component combinations where there was little or no evidence to date of degradation in the plants but where there was sufficient evidence from laboratory investigations to indicate that degradation in the plants might be expected in the future. Andresen et al. (2007) has identified specific degradation mode-component combinations where the knowledge level of the system interdependencies is low and additional proactive actions (such as research) may be warranted if PMMD by mitigation is desired.

The overall approach to developing a proactive management program for materials degradation involves two steps. The first is to identify the components of interest that might undergo future degradation as completed in Andresen et al. (2007) (also sometimes referred to as proactive materials degradation assessment, PMDA). The second step is to identify the technical gaps in plant programs that detect, characterize, and monitor stressors for degradation in all LWR components susceptible to future degradation. The technical gaps may require dedicated research projects to address the identified technical deficiency (e.g., develop effective mitigation strategies, in-service inspection (ISI) and on-line monitoring techniques, and repair procedures).

## 4 EVALUATION OF EMERGING NDE TECHNOLOGIES AND TECHNIQUES

The various techniques that can be used to sense and monitor early stage degradation were recently reviewed by Bond et al. (2009). If some of these techniques are to be deployed, it will be necessary to develop and then apply an evaluation methodology. Such a five-step evaluation methodology for new NDE techniques has been described by Cumblidge et al. (2009) and applied to monitoring using acoustic emission. Each of

[2] The NRC regulates the maximum power level at which a commercial NPP may operate. With other data, this power level is used in many of the licensing analyses that demonstrate plant safety. This power level is also included in the license and technical specifications for the plant. The NRC controls any change to a license or technical specification, and the licensee may alter these documents only after NRC approves the licensee's application for change. The definition of power uprate is the process of increasing the maximum power level at which a commercial NPP may operate.

these steps has been performed for many of the current NDE techniques, for many NPP components, but often in an incomplete manner. The five steps consist of:

- Definition of Inspection Parameters
- Technical Evaluation
- Laboratory Testing and Experimental Validation
- Round Robin Testing
- Design of a Performance Demonstration Program

Step 1: Definition of Inspection Parameters

Before any evaluation can take place, the technique and the degradation mechanism that the technique is to investigate need to be well defined. Without a solid understanding of the ISI technique and the degradation mechanism, the evaluation may be compromised. The goals and the implementation of the technique also need to be defined. The goals of an NDE technique can range from detecting very small crack precursors to detecting leakage after a flaw has propagated entirely through the component. While techniques like visual examinations for leakage are among the least desirable ways to discover a new form of degradation, visual examinations for leakage have been extremely important in maintaining NPP safety and should remain in the ISI program.

These definitions are needed to set the framework for the evaluation. At this stage, the determination can be made whether the scope of the technique is sufficient and whether there is a potential improvement in safety. Basic questions that need to be addressed for an evaluation of a technique are:

- What is the fundamental physics behind the technique/procedure?
- What types of degradation is the technique/procedure designed to be able to detect?
- How is success for the technique/procedure measured? Options include:
  a) Adequate POD curves for the technique/procedure.
  b) Assurance that failure will not occur based on the ISI program and POD results, degradation growth rates, and a probabilistic risk assessment PRA. The requirements for this determination will be based on safety factors needed to detect the degradation before it reaches a critical level. This critical level will need to be determined with input from the NRC and have a solid technical basis in order to defend this when presenting to consensus code bodies and pursuing adoption.
  c) Evidence that applying the technique/procedure will reduce the probability of failure (i.e., the use of this technique will provide a measurable benefit to safety).
- What are the technique/procedure essential variables?

Step 2: Technical Evaluation

Once the major variables have been defined for a technique, a detailed technical evaluation should be performed. Independent experts should examine the technologies to determine their theoretical capabilities and limitations. The experts performing the evaluation need to be clear of any conflicts of interest related to the technology being evaluated.

Both literature review and mathematical modelling of the physics underlying the technique should be conducted to determine whether the technology has merit and whether further testing is warranted. This review should address issues such as capability (can the system possibly detect the degradation), access (can the technique be deployed to the affected region or regions), and timing (is the inspection interval sufficient to deal with the degradation rate).

Step 3: Laboratory Testing and Experimental Validation

After a detailed review, the selected technologies should be tested in a laboratory to determine their effectiveness under a variety of conditions. These tests should provide a basis for understanding the capabilities and limits of the technologies. The essential variables should be tested and the effects of changing these variables should be evaluated.

The laboratory testing required to evaluate the technology should be highly dependent on the technique essential variables as well as how and when it is to be used. The technique should be tested under realistic conditions to assure that the NPP environment does not adversely affect the testing. Techniques that are to be used while the NPP is at full power would possibly have to be experimentally tested under simulated conditions to determine the effects of high temperatures and radiation on the equipment. One could expect that a technique that uses sensitive radiation detectors, such as standard scintillation detectors, would be adversely affected by the large radiation fields produced by a reactor. While such a technique may have technical merit, it may not be usable under NPP operating conditions.

Step 4: Round Robin Testing

To estimate how effectively the system would work for field inspections, a round-robin test should be performed using NDE inspection vendors and realistic samples. These tests should quantify, under controlled conditions, the effectiveness of the equipment and procedures to be used by inspectors in the field. This testing would ideally be performed using a double blind and statistically designed round-robin test. In current international practice, the tests performed under the European Network for Inspection and Qualification (ENIQ) protocols are not necessarily blind trials (ENIQ 2007). The individual being tested needs to demonstrate to a proctor that he is able to detect the flaw.

Step 5: Design of a Performance Demonstration Program

Performance demonstration has been an important part of the U.S. and international nuclear NDT programs. The performance demonstration requirements specified in ASME Boiler and Pressure Vessel (BPV) Code Section XI, Appendix VIII have been shown to have had a positive effect on inspection reliability (Doctor 2007). If it is determined that the technology is skill-dependent, and that anyone who uses the technology must demonstrate their proficiency with this technology, then a performance demonstration (PD) test should be designed, if PD testing is feasible for the technology. The PD should be designed to assure that the inspector, technique, procedure, and technology can achieve an acceptable performance level such as a POD with a sufficiently low false call rate, consistent with a standard such as the current requirements in Appendix VIII of ASME Code Section XI.

### **4.1** Performance demonstration considerations for continuous online monitoring

The deployment of Continuous Online Monitoring Systems (COMS), data acquisition, and the interpretation of data are significantly different than most conventional NDE systems used for ISI. It is anticipated that the COMS will be used for long periods of time while the plant is in operation (e.g., continuously) and data will be provided in near-real time. It will not require systems to be evaluated when systems are off-line as is traditionally done during ISI. The performance demonstration considerations include:

- Technical justification, which involves developing a document that describes the supporting evidence or technical basis used to provide engineering evidence that the candidate methodology will detect/characterize degradation reliably and accurately
- Procedure/equipment demonstration requirements
- Personnel demonstration requirements.

### **4.2** Technical justification

The "European methodology for qualification of non-destructive tests," documented in the second issue of EUR 17299 EN (ENIQ 1997), requires a technical justification to be developed as part of the qualification process. ENIQ requires a technical justification because the cost and development of a practical test will most likely limit the number of test pieces that can be used for inspection qualification (ENIQ 2007). Therefore, test piece trials can often only provide limited information on the performance of an NDT system. The Technical Justification achieves the following objectives:

- Document any limitations by citing all the evidence that supports an assessment of the capability of the NDT methodology and system to perform to the required level – in this case, COMS.
- Complement and provide evidence to generalize any practical trials results by demonstrating that the results obtained on the specific defects in the test pieces would equally well have been obtained for any other of the possible defects.
- Provide a sound technical basis for designing efficient test piece trials.
- Provide a technical basis for the selection of the essential parameters of the NDT system and their valid range.

The information in the Technical Justification addresses the following specific topics:

- Measurements on practice test pieces, if relevant
- Physical reasoning/basis for the monitoring technology

- Feedback from field experience
- Previous qualifications (where available)
- Relevant round-robin trials
- Feasibility studies and industrialization trials
- Mathematical models (where available)
- Laboratory studies (where relevant)
- Description of the equipment by the manufacturer
- Experimental development results

EUR 18099 EN, “ENIQ Recommended Practice 2: Recommended Contents for a Technical Justification,” Issue 1 (ENIQ 1998) is an excellent resource that may be used in developing a technical justification.

### **4.3** Procedure demonstration requirements

ASME BPV Code Section XI, Appendix VIII does not contain separate demonstration requirements for procedures versus personnel or equipment demonstrations. However, some supplements require that for a procedure to be qualified it must demonstrate the detection of all flaws in the equivalent of at least three personnel demonstration test sets. As long as the whole inspection system of instrumentation, procedure, and personnel successfully meet the qualification requirements specified in Appendix VIII, then the system is qualified. The only exception to this methodology is a new ASME BPV Code Case N-773 that is being developed as an alternative to the requirements in Appendix VIII for eddy current methods that are used in a complementary surface examination conducted from the inside surface of austenitic stainless steel or dissimilar metal piping welds, or austenitic clad piping as an aid to the qualified Appendix VIII ultrasonic examination being performed.

At the time this paper is being prepared, Code Case N-773 has just passed the Section XI approval process but has not yet been published. It provides for separate demonstration requirements for procedures and equipment versus personnel. The code case requires “open” trials where the procedure and equipment are required to pass a non-blind or “open” demonstration, defined as a test where personnel may have specific knowledge of defect locations in the test specimens.

This same concept could, and the authors believe should, be used for COMS systems. Accomplishing this goal will require the definition and use of a Performance Demonstration Administrator (PDA). Code Case N-773 states that the PDA shall be certified to at least Level II in the eddy current test method and has responsibility for the following:

- Validation and control of test specimens and documentation of qualification results
- Verification that the procedure content meets the appropriate specifications and that the procedure examination, equipment, and the data acquisition and analysis of examination data according to procedure instructions are adequate to pass the open trial
- Selection of the flaws to be included in the test sample set, administer and grade the examination in accordance with the appropriate criteria.

The acceptance criteria for the procedure and equipment demonstration should be quite stringent because subsequent personnel qualifications are blind, personnel must strictly follow the procedure and should lead to high personnel pass rates.

### **4.4** Personnel Performance Demonstration Requirements

After attempting to develop prescriptive requirements for reliable inspection and failing, the 1989 Addenda of Section XI of the ASME Code adopted performance demonstration requirements that used blind trials to demonstrate that an inspection system was capable of reliably detecting service-induced cracks.

To provide a quantifiable measure of reliability for COMS that may be used to detect and monitor degradation that occurs in nuclear power plants, the authors believe that it is essential for personnel who interpret COMS data to demonstrate an acceptable reliability through blind performance trials.

The deployment of COMS data acquisition and the interpretation of data are significantly different than most conventional NDE systems used for ISI. The difference is that the system is used for long periods of time while the plant is in operation (e.g., continuously), and it is not anticipated that the data will be monitored in real time or near real time as is traditionally done during ISI.

Therefore, the design of blind trials for personnel performance demonstration, such as those specified in Section XI, Appendix VIII will not be appropriate for COMS. The following attributes should be part of the blind trials used for personnel performance demonstration:

- Personnel qualification should include both a written and practical examination, with the written examination ensuring that the candidate understands the theory of the COMS method employed, limitations of the methodology, and the source of relevant and non-relevant signals.
- The practical examination should consist of data sets that are randomly selected and contain indications indicative of all damage mechanisms and non-relevant noise sources that could be experienced in the situation being monitored.
- The practical examination should contain sufficient data so that the candidate can demonstrate a desired performance level; for example, a passing score of 90% correct data interpretation with a 90% confidence level and no more than a 10% incorrect interpretation rate.
- Requalification should be required if a new technique causing a change in the procedure's essential variables is made or a new damage mechanism becomes an issue.

## 5 CONCLUSION

This paper has identified a need for becoming proactive in managing materials degradation in nuclear power plants as they continue to age while receiving license renewals for subsequent operating extensions. In order to be proactive, advanced and new NDE approaches will be needed. For fast-growing degradation processes or where access may be limited, there is a need for continuous on-line monitoring systems. The COMS will require extensive testing and new approaches to demonstration their reliability and effectiveness in comparison and contrast to periodic NDE as demonstrated under the requirements of ASME Code Section XI Appendix VIII. Some ideas were presented on how to apply these concepts to COMS.

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## REFERENCES

Andresen, P. L., Ford, F. P., Gott, K., Jones, R. L., Scott, P. M., Shoji, T., Staehle, R. W. and Tapping, R. L. 2007. Expert Panel Report on Proactive Materials Degradation Assessment. Washington, DC: U.S. Nuclear Regulatory Commission. NUREG/CR-6923, BNL-NUREG-77111-2006.

ANS. 2009. 6th International Topical Meeting on Nuclear Plant Instrumentation, Control, and Human-Machine Interface Technologies, Knoxville, Tennessee. April 5-9, 2009. American Nuclear Society, La Grange Park, Illinois.

Bond, L. J., Doctor, S. R., Griffin, J. W., Hull, A. B. and Malik, S. N. 2009. Damage Assessment Technologies for Prognostics and Proactive Management of Materials Degradation (PMMD). In 6th International Topical Meeting on Nuclear Plant Instrumentation, Control, and Human-Machine Interface Technologies, Knoxville, Tennessee. April 5-9, 2009. American Nuclear Society, La Grange Park, Illinois.

Bond, L. J., Doctor, S. R., Jarrell, D. B. and Bond, J. W. D. 2007. Improved Economics of Nuclear Plant Life Management. In Second International Symposium on Nuclear Power Plant Life Management. Shanghai, China, October 15-18, 2007. IAEA Paper IAEA-CN-155-008KS, International Atomic Energy Agency. IAEA Paper IAEA-CN-155-008KS, 22 pp. (in press).

Bond, L. J., Doctor, S. R. and Taylor, T. T. 2008a. Proactive Management of Materials Degradation - A Review of Principles and Programs. Richland, Washington: Pacific Northwest National Laboratory. PNNL-17779.

Bond, L. J., Taylor, T. T., Doctor, S. R., Hull, A. B. and Malik, S. N. 2008b. Proactive Management of Materials Degradation. In International Conference on Prognostics and Health Management 2008, Denver, Colorado. October 6-9, 2008. IEEE Reliability Society Paper #OP-20-01-120. ISNB 9778-1-4224-1936-4/08.

Cumblidge, S. E., Doctor, S. R., Bond, L. J., Taylor, T. T., Lupold, T. R., Hull, A. B. and Malik, S. N. 2009. Analysis of Emerging NDE Techniques: Methods for Evaluating and Implementing Continuous Online Monitoring. In 17th International Conference on Nuclear Engineering (ICONE). Brussels, Belgium, July 12-16, 2009. ASME, New York.

Doctor, S. R. 2007. Nuclear Power Plant NDE Challenges - Past, Present, and Future. In Review of Progress in Quantitative Nondestructive Evaluation. Portland, Oregon, July 30-August 4, 2006. American Institute of Physics. P. 17-31.

ENIQ. 1997. European Methodology for Qualification of Non-Destructive Testing - Second Issue. Luxembourg, Germany: European Network for Inspection and Qualification. ENIQ.SC(96)2, EUR 22906 EN.

ENIQ. 1998. ENIQ Recommended Practice 2: Recommended Contents for a Technical Justification - Issue 1. Luxembourg, Germany: European Network for Inspection and Qualification. ENIQ Report nr. 4, EUR 18099 EN.

ENIQ. 2007. European Methodology for Qualification of Non-Destructive Testing - Third Issue. Luxembourg, Germany: European Network for Inspection and Qualification. ENIQ Report nr. 31, EUR 22906 EN.

NRC. 2005a. Generic Aging Lessons Learned (GALL) Report - Summary. Washington, DC: Office of Nuclear Reactor Regulations, U.S. Nuclear Regulatory Commission. NUREG-1801, Vol. 1, Rev. 1.

NRC. 2005b. Generic Aging Lessons Learned (GALL) Report - Tabulation of Results. Washington, DC: Office of Nuclear Reactor Regulations, U.S. Nuclear Regulatory Commission. NUREG-1801, Vol. 2, Rev. 1.

WNA. 2009. The Economics of Nuclear Power. London: World Nuclear Association. Information paper. Available at http://www.world-nuclear.org/info/default.aspx?id=410&terms=Economics .