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ENHANCED HUMAN PERFORMANCE OF UTILITY MAINTENANCE PROGRAMS

Anthony Fresco, Sonja Haber and John O'Brien
Brookhaven National Laboratory
Department of Nuclear Energy
Upton, New York 11973

ABSTRACT

Assuring the safe operation of a nuclear power plant depends, to a large extent, on how effectively one understands and manages the aging-related degradation that occurs in structures, systems, and components (SSCs). Aging-related degradation is typically managed through a nuclear plant's maintenance program. A review of 44 Maintenance Team Inspection (MTI) Reports indicated that while some plant organizations appeared to assume a proactive mode in preventing aging-related failures of their SSCs important to safety, others seemed to be taking a passive or reactive mode. Across all plants, what is clearly needed, is a strong recognition of the importance of aging-related degradation and the use of existing organizational assets to effectively detect and mitigate those effects. Many of those assets can be enhanced by the consideration of organizational and management factors necessary for the implementation of an effective aging management program.

BACKGROUND

Assuring the safe operation of a nuclear power plant depends, to a large extent, on how effectively one understands and manages the aging-related degradation that occurs in structures, systems, and components (SSCs). During the plant's original licensing process, the utilities and the U.S. Nuclear Regulatory Commission (NRC) use all available sources including equipment qualification (EQ) results, industry standards and practices, and vendor recommendations, to ensure that, during the life of a plant, all SSCs remain able to accomplish their design functions. Utility EQ programs establish requirements for selected safety-related SSCs, and outline operational and maintenance practices that should prevent any such failure during the life of the plant. These practices include periodic testing and inspection, replacement and refurbishment, condition monitoring, trending, reconditioning and lubricating, and performing advanced testing for early detection of incipient failures.

After over two decades of experience, the commercial nuclear power industry has many sources of information, such as regular NRC inspections, 10 CFR Part 21 reports by vendors, NRC Generic Letters, Bulletins, Information Notices, and research activities, including the Nuclear Plant Aging Research (NPAR) program. These sources have indicated that failures of SCCs, even safety-related items, do occur in spite of all the activities imposed by the original licensing requirements. In recognition of this fact, the NRC implemented a team inspection program to evaluate and assess the current maintenance practices in place at all nuclear power plant facilities.

From 1988 to 1991, the staff of the Nuclear Regulatory Commission conducted Maintenance Team Inspections (MTIs) at commercial nuclear power plants to evaluate the effectiveness of licensee maintenance activities and to determine the need for a maintenance rule. The inspections were performance-based, directed toward evaluating equipment conditions; observing in-process maintenance activities; reviewing equipment histories and records; and evaluating performance indicators, maintenance control procedures, and the overall maintenance program. The team selected certain systems and directed the inspection toward determining whether those systems were being properly maintained. In addition, the team assessed if the current maintenance activities would ensure proper function for the remaining life of the plant.[1]

On July 10, 1991, the NRC published 10 CFR 50.65, "Requirements for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants." The rule is to become effective on July 10, 1996. The Commission noted in the Federal Register that there is a clear link between effective maintenance and safety as it relates to such factors as number of transients and challenges to safety systems and the associated need for operability, availability, and reliability of safety equipment. Good maintenance also provides assurance that failures of other than safety-related SSCs that could initiate or adversely affect a transient or accident

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are minimized and that such an approach is consistent with the defense-in-depth philosophy. Maintenance is also important to ensure that design assumptions and margins in the original design basis are either maintained or not unacceptably degraded.

The Commission further noted that the results of the MTIs indicated that licensees have adequate maintenance programs and have exhibited an improving trend in program implementation. However, some common maintenance-related weaknesses were identified, such as inadequate root-cause analysis leading to repetitive failures, lack of equipment performance trending, and the consideration of plant risk in the prioritization, planning and scheduling of maintenance. In general, as evidenced by plant operational performance data and the results of NRC assessments, the industry has exhibited a favorable trend in maintenance performance. Nevertheless, the necessity for ongoing results-oriented assessments of maintenance effectiveness is indicated by the fact that despite significant industry accomplishment in the areas of maintenance program content and implementation, plant events caused by the degradation or failure of plant equipment continue to occur as a result of ineffective maintenance. Additionally, operational events have been exacerbated by or resulted from plant equipment being unavailable due to maintenance activities.

In its summary in the Federal Register, the Commission stated its belief that to maintain safety, it is necessary to monitor the effectiveness of maintenance, and take timely and corrective action, where necessary, to ensure continuing effectiveness of maintenance for the lifetime of nuclear power plants, particularly as plants age. The rule requires that licensees monitor the performance or condition of certain SSCs against licensee-established goals in a manner sufficient to provide reasonable assurance that those SSCs will be capable of performing their intended functions. Such monitoring may take into account industry-wide operating experience Where monitoring proves unnecessary, the licensees are permitted to rely upon an appropriate preventive maintenance program. The licensees are required to evaluate the overall effectiveness of their maintenance programs on at least an annual basis, again taking into account industry-wide operating experience, and adjust their programs where necessary to ensure that the prevention of failures is appropriately balanced against the unavailability of the SSCs. For monitoring and maintenance activities which require taking equipment out of service, licensees should assess the total plant equipment that is out of service and determine the overall effect on the performance of safety functions.

In the interim period until final implementation of the maintenance rule, the industry as represented by The Nuclear Management and Resources Council (NUMARC) has drafted a regulatory guide with NRC oversight (NUMARC 93-01)[2] and prepared a report to identify all the SSCs subject to the various requirements of the rule based on results obtained from nine participating nuclear plants.

MAINTENANCE TEAM INSPECTION REPORTS

There are a total of 67 MTI reports, one for each site. For the purpose of this paper, a representative sample of 44 reports, which were issued through the end of 1990 and were readily available, was selected. These 44 reports correspond to 29 Westinghouse Pressurized Water Reactors (PWR) units, 16 Combustion Engineering PWR units, one Babcock & Wilcox PWR unit, and 22 General Electric Boiling Water Reactors (BWR) units. The reports themselves are comprehensive documents, and were prepared by different teams of NRC inspectors. The inspections were conducted using the guidance provided in NRC Temporary Instruction 2515/97[3] which includes a Maintenance Inspection Tree. The selection of systems inspected was also different from one site to another.

The major areas of utility maintenance programs which were evaluated by the NRC included (a) Overall Plant Performance Related to Maintenance, (b) Management Support of Maintenance, and (c) Maintenance Implementation. Diverse information reflecting the following aging related elements were compiled and sorted:

- Specific aging-related insights or management responsiveness to aging concerns,
- Preventive maintenance and incorporation of manufacturers' recommendations,
- Predictive maintenance and condition monitoring techniques,
- Post maintenance testing,
- Failure trending analysis,
- Root cause analysis or failure analysis, and
- Use of Probabilistic Risk Analysis (PRA) in the maintenance programs.

Findings in these seven broad categories were based on the evaluation of the entire MTI report in the light of their (a) positive aspects or attributes, (b) observation of neutral aspects, (c) negative aspect or deficiency, (d) failure, usually a direct reference to a specific system or component, and (e) violations identified by the NRC staff.

Substantial insights were gained for all of the categories analyzed. Both notable positive features as well as areas requiring improvement were identified. For the systems and components, the insights were compared to the results presented in NUREG/CR-5643, "Insights Gained from Aging Research."[4]

Although several notable programmatic practices were evident, such as a 13-week "rolling" maintenance schedule in which an entire train of safety-related components is taken out of service for maintenance and surveillance testing, and the micro-electronic surveillance and

calibration system (MESAC), designed and developed at the Braidwood plant to dynamically test instrument systems, the number and extent of weaknesses in all areas including, preventive maintenance, predictive maintenance and condition monitoring, post-maintenance testing, trending analysis, root cause analysis, and the use of probabilistic risk assessment, lead to the general conclusion that programmatic maintenance activities require significant improvement.

For maintenance activities of specific systems, there were serious failures to perform periodic testing of, or to incorporate vendor recommendations for auxiliary feedwater pumps and turbines. Preventive maintenance was often poor for instrument air and emergency diesel generator air start systems and compressors. Poor maintenance practices were noted for components such as emergency diesel generators, breakers, and switchgear. Overall improvement was shown with respect to motor-operated valves and check valves.

The general conclusion as a result of this review is that the management of aging is typically not adequately addressed by existing maintenance programs. This is based on the overall lack of specific aging management programs and notable deficiencies in preventive and predictive maintenance, post-maintenance testing, failure trending, and root cause analysis. The authors believe that widespread implementation of the many positive maintenance activities identified in the MTI reports, as well as a direct effort to improve the management of aging, would enhance the effectiveness of maintenance programs, and thereby further improve the level of safety of nuclear power plants. Since a plant's maintenance program is the principal vehicle through which aging-related degradation is managed, organization and management factors important to such a program and which should be considered in implementing each of the activities required in managing the effects of aging are discussed. Since all plants have infrastructures in place that can deal with the effects of aging, these organization and management factors can heighten utility awareness of the importance of aging related degradation and of the use of existing organizational assets to effectively detect and mitigate aging effects.[5]

ORGANIZATION AND MANAGEMENT FACTORS

In reviewing the technical knowledge relevant to an aging management program as identified by the MTI reports and to some extent the Phase I and Phase II NPAR studies, several organization and management factors necessary for the effective implementation of programs to address aging are clearly relevant.

The Nuclear Organization and Management Analysis Concept was developed as part of an effort to identify scientifically valid and acceptable techniques to examine and assess the broad influence of organizational factors on nuclear power plant safety. The concept is a description of the human organization of a plant and its utility lies in the fact that it is a dynamic, interactive, and behavior-oriented characterization of the plant, emphasizing functional relationships between units. Based on the results obtained from field-testing of the concept and its associated methodology, organizational factors important for safety performance have been identified. These factors are: communication; standardization of work; decision-making and problem-solving; management attention, involvement and oversight; and organizational culture.[6] Subsequent work has modified the factors slightly and various applications of these factors have identified more specific dimensions relevant to particular operational characteristics, but the primary concepts have remained.[7]

The factors most likely to affect a utility aging management program can be classified into the following six categories:

- communication
- standardization of work and skills
- human resources
- cultural awareness
- decision-making
- organizational skills

An understanding of how these factors can impact the implementation of the overall aging management in the plant is critical for effective performance. A close relationship exists between these factors and the technical activities required to effectively manage a maintenance program that will also address aging issues. Each of the organizational factors is described below by way of example to its potential impact on the implementation of an effective aging management program.[8]

- Communication

  The overall maintenance of a nuclear facility is performed by a number of departments within the plant. For example, a typical plant has mechanical, electrical and I&C engineering and maintenance staffs, and an operating staff. It is imperative that good interdepartmental and intradepartmental communications exist within the plant so that responsible individuals can share their experiences and knowledge with each other. In addition, good communication external to the plant, specifically with other utilities that may have had similar experiences related to aging concerns can improve quality and productivity. For example, comprehensive root cause analyses of similar failed events shared by plants can provide input to several disciplines so that such an occurrence can be prevented in the future.

- Standardization of Work and Skills

  There exist numerous procedures, standards, and guidelines in operating and maintaining a nuclear power plant. These contribute to the standardization of work and skills across the plant. A large number of the activities aimed at coping with the effects of aging may result in the need for new procedures which must be standardized. These procedures must

be developed, implemented and refined. New procedures may be developed by the engineering organizational unit, implemented by middle line management, and modified using feedback from the operators and maintenance units. The outputs of the maintenance activities, among other things, will be used to develop these new procedures. Implementation of new activities in the plant to assist in the detection and mitigation of aging effects will require that training of plant staff be modified. This will result in the standardization of new skills across the plant. Training programs will have to be reviewed and examined. Modifications will include the new skills necessary to perform new PM methods and new inspection, surveillance and monitoring (ISM) practices, and to foster a clear understanding of the available aging data.

- Human Resources

  There may be reasons to modify the existing staffing plan at the plant in order to provide the increased manpower or expertise necessary to perform new or additional activities aimed at detecting and mitigating the effects of aging. An example of a staffing change may be the formation of a dedicated group, the shifting of resources, establishment of related communication protocols and lines of authority. Additional activities will include more ISM, more PM and corrective maintenance (CM), and more changes in staffing during refueling shutdowns.

- Culture

  Many of the activities necessary for successful detection and mitigation of the effects of aging involve a high level of cultural awareness within the plant organization of what occurrences may be evidence of aging-related degradation. The Phase I and II Nuclear Plant Aging Research (NPAR) studies have indicated that much of the evidence of aging related wear and tear is very subtle. Much of the awareness necessary to competently identify deleterious effects of aging is related to a comprehensive understanding of how the plant changes over time. While much of this understanding can be conveyed in training programs, it is important to ensure that the entire plant staff maintain a vigilance and cultural awareness of these indicators. A significant cultural value in the organization must be to enhance sensitivity to these indicators.

- Decision-making

  Decision-making is a complex process involving, among other things, coordination of work performed by different people within the organization. Centralizing work and other information, and prioritizing the goals of aging-related activities, often facilitate making the optimal decisions while performing maintenance or other tasks. These measures help management staff to reallocate both human and financial resources to achieve the proper goals.

- Organizational Skills

  Organizational skills are the set of skills an organization uses to effectively operate, manage, and maintain its facility. The more skillful an organization, the more effectively it operates. These skills include the general knowledge level within the organization of how its administrative, managerial, and structural systems operate, the ability of the organization to learn from new information or past experience, and the general level of technical knowledge of how the plant operates. These skills are critical in implementing an aging management program.

EFFECTIVE AGING MANAGEMENT

Effective aging management practices at a nuclear facility require consideration of both technical and organization and management factors that are important for understanding, detecting, and mitigating the effects of aging. The identification of the technical needs for developing such programs are presented in the MTI reports and NPAR studies on SSCs, as well as several other case studies by the NRC and the nuclear industry. The conclusions from these efforts indicate that no separate and distinct programs exist that specifically address the management of aging. The following discussions provide a framework for integrating the technical and organization and management elements to enhance the existing plant maintenance practices for effectively managing the effects of aging.

One of the most important elements for developing successful aging management practices is the attention, involvement and commitment from utility management. This includes, as an objective, achieving a better and effective plant operation, and a strong financial and resource commitment. In return, the plant's maintenance program assures that modifications to the existing programs are cost-effective for aging management, while continuing to keep the plant operating safely and reliably. The changes necessary for optimal management of aging include activities that are encompassed within several categories of the organization and management factors.

In an aging management program, either (1) a number of systems are selected which are important for reliable and safe plant operation, or (2) a number of component types are selected whose maintenance improvement can enhance plant performance in many key systems. Based on the aging studies and various case studies performed by the AEOD, EPRI, and utilities, the technical improvements in understanding, detecting, and mitigating aging problems are correlated to a plant's existing maintenance programs. Interviews and functional assessments of the facility's day-to-day maintenance activities should be performed to understand the operational modes relevant for the organization and management factors.

Each of the organization and management factors has subelements which are directly or indirectly related to implementing the technical improvements into the existing maintenance programs. The overall performance of a plant in detecting and mitigating aging can then be measured by evaluating the information obtained from all of the activities identified. A system-level or component-level reliability assessment should also be required based on the recommended changes, to fine tune the scope of these activities in achieving the initial goals for the program established by management.

CONCLUSIONS

The NRC evaluated utility maintenance programs through a systematic approach called Maintenance Team Inspections (MTI). Several areas of the review are related to how a plant understands and manages the effects of aging. A review of 44 MTI reports indicate that weaknesses exist in some portions of maintenance programs deemed important for understanding and managing aging, while others are strong or in the process of being strengthened. However, even though a site's maintenance program may have received an overall good or satisfactory rating, it does not necessarily imply that concerns related to aging-related degradation are being satisfactorily addressed. Clearly, if a site's program received a poor rating, aging-related degradation concerns are not being satisfactorily addressed.

The strongest conclusion that can be drawn from this review is that improvements in preventive and predictive maintenance programs, including failure trending and root cause analysis, together with the development of an integrated maintenance program, can significantly improve the management of aging degradation and consequently the safe operation of nuclear power plants. This paper has identified some of the programmatic and system/component aging management issues that are discussed in the NRC's MTI reports. Many of these issues concern elements that can be enhanced through the awareness and attention to organization and management factors that have been identified to influence safety performance in nuclear power plants. The integration of the technical knowledge amassed from the recent inspections and studies, with the organization and management elements, can only increase the success of utilizing existing maintenance organizational assets for the purposes of implementing an effective aging management program.

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