INTERNATIONAL ATOMIC ENERGY AGENCY

INTERNATIONAL SYMPOSIUM ON SAFETY ASPECTS OF THE
AGEING AND MAINTENANCE OF NUCLEAR POWER PLANTS

Vienna, Austria, 29 June-3 July 1987

BNL-NUREG-40049

IAEA-SM-295/ 40

MANAGING THE EFFECTS OF AGING AND RELIABILITY IMPROVEMENT*

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BNL-NUREG--40049

DE87 013299

*Work performed under the auspices of the
U.S. Nuclear Regulatory Commission

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MANAGING THE EFFECTS OF AGING AND RELIABILITY IMPROVEMENT**ABSTRACT**

Over recent years the electric power generating community has acknowledged the importance of the aging process on plant safety and availability. To cope with time-dependent degradation phenomenon that can affect active as well as passive components and lead to unacceptable, unanticipated failures requires research into the mechanisms of the aging process, advances in predictive methods for assessing the aging impact on risk and availability, and a better understanding of power plant operations so that strategies for defending against this pervasive stress can be developed. This paper discusses current research advances and present a framework to aid in the systematic integration of these three needs. As such it is anchored to research being conducted at Brookhaven National Laboratory in the areas of plant aging, life extension, reliability, performance indication, and risk assessment.

The current question facing the industry can be simply stated. "How can an acceptable level of safety and availability be maintained throughout the operational life of a nuclear power plant?" The complexity of this question indicates that managing aging effects must be a continuous, coordinated process integrated with day-to-day tactical plant operation decisions. This implies that aging and reliability programs must be systemic properties of an organization's management, and that research into aging technology must be closely linked.

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1. INTRODUCTION

To maintain and enhance the long-term satisfactory operating characteristics of a nuclear power plant one must first acknowledge the importance of the aging processes on plant safety and availability. Providing assurances of the operational readiness of aged safety systems and components during the design or extended lifetime requires assessments of how aging of safety systems, structures and components will result in increasing the potential for common-mode failures and varying levels of incipient, degraded and catastrophic failures. Essentially, the major safety issue deals with how aging can negatively affect, over time, the defense-in-depth that is designed into the system, and how this knowledge can be used to develop defensive strategies.

1.1 The Technical Issues

Addressing aging, life enhancement and extension in the context of plant safety, operational readiness of accident prevention/accident mitigating systems, plant availability, and economic power generation requires implementation of programs designed to address such issues as:

- What structures, systems, and components are susceptible to aging effects?
- What are the prevailing degradation processes which could, if unchecked, affect safety?
- How can operational readiness be assured during design and extended life?
- How do we assess the adequacy of and/or make improvements in currently available test and surveillance methods for identifying all relevant aging mechanisms before safety is affected beyond some perceived goal?
- What criteria are required to evaluate residual life and what supporting evidence will be required above and beyond the data that are presently collected and the analyses?
- Which structures, systems, and components should be selected first for comprehensive aging assessments and residual life evaluations?
- What should be the role of plant performance in making life enhancement/life extension decisions?

Aging technologies as research and development topics are, therefore, primarily related to programs that manage reliability, availability, preventive maintenance and performance monitoring, all within the purview of programs designed

to understand and evaluate the implications of those relevant aging mechanisms that can affect safety. In short, life cycle planning must include daily procedural practices at a plant with strategic policy planning to assure that an acceptable level of risk and plant availability can be maintained.

In addition, current regulations must be examined to assess whether regulations can potentially aggravate the impact of aging on the maintenance of an acceptable level of safety throughout the operational life of a nuclear power plant.

1.2 Programmatic Issues

To aid in answering these questions a two-bin model is proposed to identify aging research needs, guide technological advancement, and most importantly assure timely incorporation of research products into plant operations. The first bin, considered tactical or short-term planning, includes those current daily activities found with different degrees of success in all operating units. Such activities as normal operating practices, surveillance tests, and preventive and corrective maintenance can be considered here. The second bin is much more long term and can be termed strategic planning. This planning must review repair/replace/upgrade strategies, spare parts needs, and trade-offs to optimize preventive and corrective maintenance. It is here that planning for the next 10 years of successful operation takes place. It is here that reliability practices and enhanced plant performance monitoring are considered. It is here that aging problems are diagnosed and research needs established.

The general issues associated with and the complexities involved in long-range, strategic planning and its relationship to day-to-day, tactical plant operation decisions and aging technology are:

1. Performance Criteria: Long-range strategies must address a wide range and less quantifiable set of values in determining ends to be achieved than do short-range decisions.
2. Feedback: Long-range planning requires actions now, but the major impact is seen in the future. Hence the correctness of strategies is difficult to evaluate because of the lack of immediate feedback.
3. Control: In short-term decisions, factors under the organization's control can normally be separated from those which are not. Over the long term there is less pure control over a single factor but more potential influence overall.

4. Data: Considering our current performance data and data gathering systems, the further we look into the future operating cycle of a plant, the more uncertain the data base becomes in predicting trends. Past performance may not be a good prediction of future problems unless proper indicators that monitor, trend, and could predict performance are identified, evaluated and applied.

These complexities require a continuous, coordinated process integrated with day-to-day tactical plant operation decisions and on-going research. This implies that aging, reliability, and performance monitoring programs must be systemic properties of an organization's management, i.e., what could or should be done today to achieve the desired goal of assuring the optimum operating life of a power plant tomorrow.

2. A RELIABILITY PROGRAM ARCHITECTURE - THE FOCAL POINT FOR MANAGING THE EFFECTS OF AGING

At the outset it must be stated that programs which deal with reliability/availability improvement and maintenance policies differ in their emphasis with those that stress strategies for life extension. The contrast lies in the fact that these programs naturally focus on active components, such as rotating machinery and those components which are routinely replaced. Life extension, on the other hand, should be more focused on passive potentially non-replacable elements, such as pressure boundaries, structural components and those components whose intervals between replacement or major refurbishment are large, if at all possible.

Regardless of these differences, the two programs, i.e., reliability enhancement and life-extension, should be closely linked because there is mutual benefit to be gained. A decision regarding corrective maintenance on an older piece of equipment might be to replace it if the plant is allowed to operate for longer periods. Likewise, it may be easier to spend proportionately greater amounts of maintenance if those expenditures will support longer operating life commensurate with maintaining an acceptable level of risk.

The basic interest therefore is the determination of life-limiting mechanisms, known or perceived, which impact the service lifetime of passive and active components. A life limiting study essentially defines a calendar of anticipated times when components will have to be examined and assessments made on the refurbishment/replacement options. Planning may indicate those changes which could be made now (the tactical decisions) to insure that the option of long-term operation remains open, e.g., reduction of fatigue or radiation damage to those pressure boundary components which are difficult to replace and which have a direct impact on safety. Two categories of activities that can (and should) be implemented quickly are improved monitoring and record keeping and the

identification of age-related degradation control and mitigation programs. An anticipated near-term benefit for strategic planning is improved reliability. Daily operational activities, such as condition monitoring, and maintenance planning have the potential of reducing forced outages and transients through planned corrective/preventive actions. Accordingly, a viable reliability program should be considered to be the focal point for managing the effects of aging.

2.1 Reliability Program - Salient Features

A reliability program should be structured to provide a means for recognizing when a reliability problem exists (and conversely, recognizing when equipment reliability is satisfactory). It should be capable of anticipating, or prognosticating, potential reliability problems based upon present signs and symptoms observed through evaluations. These evaluations should be able to indicate design or testing inadequacies, vulnerability to common-cause failures, observed deterioration and identify whether or not problems that have occurred elsewhere in the industry can occur locally. Failures that have been detected, localized, and classified by failure mode and severity should be prioritized for corrective action. Priorities for corrective action should be established a priori depending upon the importance of the component/subsystem in meeting the mission requirements of the overall system and the severity of the failure. Failures should therefore be corrected in a time frame commensurate with the importance of the incipient degraded or failed component. The reliability program process should then provide assurance that the proper corrective actions have been taken and that the results of such actions are monitored over the long term to assure proper closeout of the problem.

A reliability program therefore must apply different methodologies based on aging technology to assess and survey the condition and performance of a system throughout its entire operating lifetime so as to obtain a diagnosis of failures and deteriorations and must institute measures for increasing (or maintaining) the operational readiness of the system in concert with the potentially changing safety importance of the system.

Unlike most industries, nuclear power plants employ a large amount of standby equipment. In order to import the above characteristics for standby safety equipment, the program should a priori define and specify the following:

- The equipment to be included in the program.
- Reliability targets based at least partially on the equipment's importance to safety.

- The types of surveillance techniques that will be used, based on expected aging phenomena and operating characteristics.
- The test and inspection intervals for each surveillance type.
- The list of incipient conditions that are triggers for performing preventive maintenance.
- A list of observables and information to be fed into various component performance monitoring schemes.
- Performance monitoring analyses, computations, and guidelines for determining if a potential reliability or availability problem is evident or if the proper corrective action to a diagnosed reliability problems has been taken.

In summary, the basic elements a reliability program should possess include:

- performance monitoring determination and evaluation based on aging technology insights,
- problem identification and analysis based on plant experience,
- problem prioritization and corrective action identification, anchored to importance and failure severity, and
- corrective action implementation, verification, and feedback to plant operations and to aging research.

In general, requirements associated with each of these elements and the applicability of reliability technology to LWR operational safety are depicted in Figure 1 and discussed more fully in NUREG/CR-4618, May 1986.

2.2 Assessing the Effects of Aging on Plant Reliability

An aging research program must have the compatible goals of 1) identifying those aging and service wear effects that can impair plant safety and availability, 2) identifying those methods of inspection, surveillance, and monitoring which will assure timely detection of significant aging effects where necessary prior to loss of function, and 3) evaluating the effectiveness of corrective and predictive maintenance practices in strategic planning. It is this output that provides the necessary data for a reliability program such that its focus will become aging oriented.

Aging technology must be used to initiate a reliability program that addresses strategic plant operations. As such, equipment and system-specific operating experience, augmented by the results of age-related analysis and experiments such as those ongoing at Brookhaven National Laboratory (BNL), input into element 1 of Figure 1. Once the process has begun, problem prioritization and cause identification, elements 2 and 3, should feed back to research where and when the technological bases for real time decision needed in elements 4 and 5 are uncertain or non-existent. An aging technology anchor is also required to address the effectiveness of plant fixes, element 6, through predictive models and to identify adequate performance monitoring techniques, element 7. There must exist in all these an inherent link between plant operations, a reliability management program, and aging technology. The quality and completeness of strategic as well as tactical decision making depends on the strength of those ties.

3. ENHANCING OPERATIONAL RELIABILITY

Research is currently being conducted to refine and demonstrate nuclear reliability approaches, appropriate risk prioritization schemes, statistical indicators to trend system performance and direct, risk-based, predictive indicators of plant performance. In addition, based on a risk prioritization conducted by the U.S. Nuclear Regulatory Commission, an analytical and experimental aging research program is addressing the details needed to implement the management approach present in this paper on components (electric motors, battery chargers and inverters, circuit breakers and relays, actuation channels and trip modules) and systems (reactor coolant pump seals, component cooling water, residual heat removal, control rod drive). This research being undertaken at BNL and elsewhere has been structured to address the technical and programmatic issues listed in Section 1. Specific to BNL's role in this research, two examples will be highlighted: one which emphasizes identification and classification of age-related failure mechanisms on components (electric motors) whose sheer numbers in nuclear plant systems can impact safety (NUREG-CR-4939); the other example (diesel generator) emphasizing strategies to enhance the operational readiness of an important, accident-mitigating system and in obtaining statistically unbiased estimate of system performance (BNL Technical Report A-3282, 4-15-86).

Electrically driven equipment is required for all modes of operation of a nuclear power plant. A count of the number of electric motors in a typical pressurized or boiling water reactor found approximately 1100 units in a given plant. These motors are, dependent on application, subjected to continuous duty cycles, intermittent operation, and long-term standby for safety systems. They may operate in mild environments as well as harsh, and in selected accident cases could

be required to change from a stand-by mode to one of continuous duty. Because of the diverse application of electric motors and the number of units in use in a plant, the contribution to risk is not in all cases obvious. The industry tends to look at the driven equipment importance when deciding the fate of the motor. In general motors themselves experience little preventive test and maintenance, and performance trending is rarely seen. However, a recent BNL aging assessment has shown that although electric motors are rugged pieces of equipment, they demonstrate long-term time dependent failure characteristics, a dependence that can be observed and defended against through adequate application of the methodology described early in this paper. The long-term failures, as observed in historical as well as experimental data, occur in the dielectric integrity, typically the stator, and the rotation integrity, typically the bearings. A strategic application of reliability management is required to focus the plant's attention on only that subset of electric motors that singularly or as age-caused common failures can impact safety and availability. A decision to rely on visual inspection, performance monitoring, and preventive maintenance to defend against catastrophic failures due to motor aging would be practical when a motor is found to be important to plant function, or is difficult to replace when failed due to location or availability of a replacement. In these cases, tactical activities such as visual inspection that can identify gross integrity breakdown linked with monitoring schemes that are used to trend the more subtle parametric changes due to age can guide strategic decision making.

Now turning our attention to the question of aging impact on emergency diesel generator reliability, the question that arises is how to reduce the wear effects of testing on the unit while still assuring operational readiness. Because of the complexity of this system and the difficulty in developing an understanding of the failure mechanisms at the piece part level, a system performance model was built.

As a first step in developing strategies to enhance and extend the operational readiness of diesel generators, models have been developed to evaluate risk-effective surveillance testing of diesels that can differentiate between accident and test unavailability. The models show that there can be large differences between accident and test unavailabilities; they identify the major contributors of the diesel's failure to start either in a test or during a true demand, and introduce system-level indicators that could be used to monitor system performance. (Work is currently in progress (BNL Technical Report A-3295 5-26-87) on constructing/simulating statistically unbiased indicators of system unavailability.) The models allow optimal test intervals to be simply determined for any set of diesel parameters. Figure 2 shows the optimal test interval (days) versus diesel standby failure rate (λ) for different down times d (in hours). With present diesel

data, estimates of more risk-effective test intervals can be modeled. Once these parameters are linked with products from aging research they could be expanded to address how surveillance test intervals could be modified to mitigate age-related failure mechanisms.

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FIGURE 1 RELIABILITY PROGRAM PROCESS

Figure 2 OPTIMAL TEST INTERVAL: DOWNTIME EFFECTS