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EVALUATION OF NRC MAINTENANCE TEAM INSPECTION REPORTS FOR MANAGING AGING*

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ABSTRACT

A plant's maintenance program is the principal vehicle through which age-related degradation is managed. Over the past two years, the NRC has evaluated the maintenance program of every nuclear power plant in the U.S. The reports issued on these in-depth team inspections have been reviewed to ascertain the strengths and weaknesses of the programs as related to the need to understand and manage the effects of aging on nuclear power plant systems, structures, and components. Selected results of this review are presented in this paper, including examples of inspection and monitoring techniques successfully used by utilities to detect degradation due to aging. Attributes of plant maintenance programs where the NRC inspectors felt that improvement was needed to properly address the aging issue are also discussed.

INTRODUCTION

Since 1988, the NRC staff has been conducting Maintenance Team Inspections (MTIs) at commercial nuclear power plants to determine the need for a maintenance rule. As outlined in an NRC Policy Statement on Maintenance dated March 23, 1988,[1] "each licensee should develop and implement a maintenance program which provides for periodic evaluation, and prompt repair of plant components, systems, and structures to assure their availability." The MTIs were conducted to inspect and evaluate the effectiveness of licensee maintenance activities. A detailed report was issued on the results of each inspection which described the strengths and weaknesses of the maintenance program and its implementation. A review and summary by the NRC of the results of 31 site inspections available through fiscal year 1989 has been previously published.[2]

It is evident that aging can be accelerated by inadequate maintenance, improper or too frequent testing, or excessive cycling from routine or abnormal operations. On the other hand, a maintenance program has important elements relevant to detecting and mitigating age-related degradation such as preventive maintenance, reliability-centered maintenance, recordkeeping and trending.

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In support of the NRC's Nuclear Plant Aging Research (NPAR) Program, the MTI reports are being independently reviewed with the following objectives in mind:

1. To assess the evaluations of those portions of the maintenance program important for understanding and managing aging.

2. To evaluate the strengths and weaknesses noted in utility maintenance programs which could affect the ability of the plant to manage aging.

3. To determine the types of preventive maintenance activities and condition monitoring techniques used which address plant aging concerns.

To achieve these objectives, inputs from each MTI report are being compiled in a computerized data base. The information extracted from the reports include observations by the inspectors related to the concept of understanding and managing aging, such as:

- specific references to equipment aging problems,
- predictive maintenance and condition monitoring techniques,
- selected preventive maintenance activities, and
- evaluation of failure trending and root cause analysis programs.

At this time, 26 of approximately 50 MTI reports have been reviewed.** These reports were issued during the period of 1988 to mid 1990. In general, these reports have provided substantial information on how plant maintenance programs address the aging of components, systems and structures. This includes the attitude of management towards the aging issue as well as the specific maintenance program attributes which address the detection or mitigation of degradation caused by aging. Preliminary results from this evaluation have been obtained and are reported in this paper. A summary of the findings to date concerning condition monitoring techniques, trending and root cause analysis appears in Table I.

SPECIFIC AGING MANAGEMENT INSIGHTS

From the reports reviewed, it can be concluded that, while some utilities have a proactive approach to preventing aging-related failures of systems and components important to safety, others seem to be taking a passive or reactive posture. Differing maintenance philosophies, and financial resources, have an impact on management attention to aging concerns. One utility considered its plant life extension program to be founded upon a strong maintenance program approach. In other cases, the reports indicated reliance upon the Environmental Qualification program as a response to aging concerns. Examples of slowness to respond or unawareness of aging concerns were also cited.

**It is difficult to properly correlate the observations in this report on the basis of the number of plants vs. the number of reports. Usually, one report was generated for each site. Each site may have more than one unit, sometimes of completely different reactor design.

Among the more positive responses to aging identification are the following examples from the reports:

- In response to a catastrophic pipe rupture in main feedwater piping, and NRC Generic Letter 89-08,[3] the inspectors credited the utility for having a well-defined program for erosion/corrosion thinning of feedwater piping.
- At another utility, scratches were found on two camshaft lobes during an inspection of an emergency diesel generator. The utility responded to this evidence of potential aging degradation by establishing a special monitoring program to detect deteriorating performance, i.e. cylinder temperature changes.
- To minimize the effects of aging, one utility has a program for dewatering its emergency diesel generator fuel oil storage tanks to control oxidation and bacterial growth. The same utility will replace steam generators in 1992, and is upgrading instrument air systems and certain service water piping in response to aging-related degradation.

Examples of lack of utility response to aging concerns are the following:

- At one utility, the safety valve failure rate was four times the industry average. For the cases where the failure modes were determined, the causes were attributed to dirt and wearout.
- At another utility, the manufacturer's instruction manual for the reactor water level switches did not specify any particular preventive maintenance requirements. However, in 1986, following a history of problems, the manufacturer's representative was called in and recommended that the switches be refurbished every 5 years. Although the switches had never been refurbished prior to that time, the utility took no action until 1988.
- At still another utility, chronic problems have occurred in the emergency diesel generator (EDG) air start system due to leaking check valves and compressors which have required frequent in-head replacement. Station personnel had identified two concerns related to aging:
  - The absence of a program for monitoring or controlling EDG air starting quality, and
  - The high likelihood that the air start receivers are full of rust and scale from years of moisture buildup.

PREVENTIVE MAINTENANCE/ PREDICTIVE MAINTENANCE AND CONDITION MONITORING

This area seems to be one in which many utilities are actively engaged either in the planning or implementation of programs. Typically, predictive maintenance and condition monitoring include practices which can be useful to detect incipient degradation due to aging effects. The most common practices are thermography, vibration monitoring, lube oil analysis, and motor-operated valve current signature or yoke strain measurement.

Thermography – Thermography is performed by utilizing heat sensitive infra-red light to take a thermal profile of the object being inspected. Abnormal heat generation is usually a sign of excessive friction or undesirable electrical contact resistance or overcurrent conditions. This method can detect looseness of electrical connections and deterioration of electrical insulation and printed circuit boards.

One utility identified the following components as subject to thermography:

- Generator current transformers
- Exciter switchgear
- Motor control centers
- Station service transformers
- 6.9 and 4.16 KV breakers
- 480V breakers
- Instrument air compressors
- Motor-generator sets
- Rod control cabinets
- Reactor trip breakers
- DC distribution panels
- Electrical penetrations

Vibration Monitoring – Vibration monitoring and trending are used frequently on continuously operated safety-related equipment such as Component Cooling Water (CCW) and Chemical and Volume Control System (CVCS) charging pumps and motors. They are also used at some plants for balance of plant (BOP) equipment such as main station turbines, main feed pump turbines, circulating water and condensate pumps, generator stator cooling water pumps, etc. Some plants, not all, monitor the auxiliary feedwater (AFW) pumps and steam turbines.

Lube Oil Analysis – Lube oil analysis is typically conducted on some safety-related equipment such as emergency diesel generators (crankcase oil), and reactor coolant and CVCS charging pumps and motors. Some plants include auxiliary feedwater, low pressure and high pressure safety injection and containment spray pumps and motors. BOP components such as the condenser vacuum system may also be included. The purpose of the lube oil analysis is to perform either a physical or chemical analysis of the oil to detect foreign substances such as metallic particles or water vapor, or to find evidence of overheating such as carbonization or property changes. Such evidence would be indicative of frictional wear and undesirable contact with a rotating surface, or heat exchanger leakage.

Testing of Motor-Operated Valves – Another key area of condition monitoring concerns safety-related motor-operated valves. A common practice is to record and trend changes in a valve motor's signature current. One such procedure is referred to by the tradename MOVATS (Motor Operated Valve Analysis and Test System). This method was heavily used in testing Limitorque valve operators, which were the subject of NRC Bulletin 85-03.[4,5]

Another means to measure MOV operability is to measure yoke strain, which is an indicator of stem thrust. This provides information for both the closed and open direction through the entire stroke. Some utilities are also implementing such a procedure, known as VOTES (Valve Operation Test Evaluation System).

Miscellaneous – Some other methods of condition monitoring or preventive maintenance which were cited in the reports are:

- MOV overhaul and diagnostic program which includes a complete inspection and lubrication of the main gear case, limit switch compartment and valve stem, and proper setting of torque and limit switches.
- MOV stroke time measurements.
- Colored photographs of MOV operator internals to show the number of limit switch rotors, whether an approved torque switch was installed, and whether there was the correct number of jumper wires, etc.
- Check valve disassembly and inspection.
- Ultrasonic testing for leakage from BOP valves.
- Erosion and corrosion monitoring of pipe wall thickness.
- Differential pressure across safety-related pumps, such as containment spray, service water, component cooling water, and auxiliary feedwater.
- Helium leak detection and eddy current testing of lube oil heat exchanger tubes.
- Terminal temperature differences (TTD) vs. time trended for feedwater heater, moisture separator reheaters and main condenser.
- Emergency diesel generator exhaust gas monitoring.
- Station battery individual cell voltages.
- 4160V metal-clad switchgear overhaul including verification of undervoltage trip attachments, breaker cleaning and inspection (with the breaker removed), cell cleaning and inspection, relay/control wiring compartment cleaning and inspection.
- Shock pulse analysis.
- Thermal shield movement monitoring program which assesses neutron flux to detect thermal shield (vessel internals) motion or movement.
- Loose parts monitoring to detect objects in the reactor coolant system by means of an accelerometer attached to the reactor vessel.
- Electrical character analysis and diagnosis (ECAD) in which electrical loop characteristics are measured to anticipate degradation in components or connections.
- Redundant Instrument Monitoring System (RIMS) which compares redundant channels for early detection of channel calibration drifts.

FAILURE TRENDING ANALYSIS

The reports indicate that most, if not all, utilities have some form of failure trending analysis. Most plants actively participate in the Nuclear Plant Reliability Data System (NPRDS) and some compare the performance of selected equipment at their plants with the industry averages in NPRDS.

Failure trending programs are an essential step in managing aging because, in their absence, identification of the contribution of age-related degradation to failure frequency cannot be properly performed. Typically, such a trending program could be based upon licensee event report (LER) data, maintenance performance indicators including Institute of Nuclear Power Operations (INPO) Standard Performance Indicators, maintenance work order statistics, and NPRDS data. Several plants utilize the Computerized History and Maintenance Planning Program (CHAMPS) which is a plant-specific maintenance data base program which can provide trending information. Proper implementation of post maintenance testing requirements is also essential to a good trending program to provide intermediate baseline reference points of equipment condition.

According to the NRC evaluation of the MTI reports through fiscal year 1989 previously cited, nearly 25% of the 31 sites were rated as poor in the area of maintenance trending, and 29% were rated as poor in the area of technical and engineering support. Weaknesses cited related to trending included the following:

- Repetitive failures of equipment were not identified as a basis for changes in the scope of the preventive maintenance program.
- Reports typically indicated gross overall trends and did not identify repetitive failures over a long period, subtle trends, or component failure trends.
- Documented information on completed work packages was not adequate to assist in root-cause analysis or aid in analyses of future trends.
- Some programs were fragmented so that a single reviewer did not see all the available information.

In our study, inadequacies in the trending program were cited for nearly half of the sites, i.e., 12 of 26. One of the specific findings resulting from our review was that in some cases the system engineers do not always receive sufficient information, either internal records such as copies of all completed maintenance work requests for their respective systems, or else external records such as NPRDS and LERs, to make informed decisions concerning the need for corrective maintenance or to identify trends of repetitive maintenance tasks, which may ultimately result in component failure. Sometimes the systems engineers are only notified when component failures reach an unacceptable level. In other cases, the compilation of computer-based histories is relatively new, so that trending of failures occurring earlier than the previous 3 to 4 years is very difficult and time-consuming.

Among the more positive findings, one utility was noted as having 19 documented trending programs, presumably either of condition monitoring or failure trending types, of which the failure trending analysis of plant-specific vs. NPRDS component failures was singled out.

ROOT CAUSE ANALYSIS

Root cause analysis is an important programmatic technique to prevent or minimize repetitive component failures, and consequently reduce maintenance backlogs and outage time. It is also important so that age-related degradation can be identified and corrective measures can be taken. RCA can involve management oversight and risk-tree analysis (MORT), causal factors analysis, change analysis, barrier analysis, fault-tree analysis, and the human performance evaluation system process.[6]

According to the NRC evaluation discussed previously, for the plants which were cited as having poor technical and engineering support of maintenance and also poor maintenance trending, the following reasons related to root cause analysis were noted:

- Repetitive failures of equipment were not identified as a basis for changes in the scope of the preventive maintenance program.
- Inadequate root-cause analyses were performed when equipment failed.
- For some preventive maintenance problems, it took more than 2 years to reach an engineering resolution. (Presumably failures could have continued to occur during this time without the root cause being addressed or identified).
- There is inadequate communication between technical support groups and maintenance groups concerning failure analysis.
- System engineers have limited time to monitor the system for which they are responsible.
- Reports typically did not identify repetitive failures over a long period, subtle trends, or component failure trends. (This could result in oversight of problems requiring root cause analysis).
- Documented information on completed work packages was not adequate to assist in root cause analysis.

From our analysis, it was observed that root cause analysis can require a very intensive effort, and given the typical large volume of maintenance work requests, it is not always given a high degree of priority at many plants, or else the scope and depth of the analyses are limited. Inadequacies in the root cause analysis program were evident in 13 of the 26 sites reviewed.

SUMMARY

The NRC teams evaluated maintenance programs through a systematic approach using management oversight and risk-tree analysis (MORT). Several modules of review are related to how a plant understands and manages the effects of aging. For example, the review of trending, root cause analysis, etc. must be accomplished in order to detect and mitigate the effects of aging. Our preliminary findings of the review of MTI reports indicates 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 receive an overall good or satisfactory rating, it does not necessarily follow that concerns related to aging-related degradation are being satisfactorily addressed. Clearly, if a site's program has a poor rating, aging-related degradation concerns cannot be satisfactorily addressed.

REFERENCES

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3. NRC Generic Letter 89-08, "Erosion/Corrosion-Induced Pipe Wall Thinning," May 2, 1989.

4. IE Bulletin No. 85-03, "Motor-Operated Valve Common Mode Failures During Plant Transients Due to Improper Switch Settings," November 15, 1985.

5. NRC Bulletin No. 85-03, Supplement 1, "Motor Operated Valve Common Mode Failures During Plant Transients Due to Improper Switch Settings," April 27, 1988.

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Table I
Aging-Related Maintenance Summary

A. Usage of Condition Monitoring Techniques

Technique[1]	**Number of Sites**[2]
Vibrational analysis	20
Thermography	14
Lube Oil analysis	16
MOV diagnostics	11
Check valve inspection	4
System parameters (e.g., setpoint drift)	4
Noise analysis, erosion/corrosion monitoring, motor insulation resistance, battery cell specific gravity, heat exchanger performance.	8

B. Inadequacies Identified in Trending and Root Cause Analysis

Technique[1]	**Number of Sites**[2]
Trending	12
Root cause analysis	13

[1]The MTI reports did not always explicitly state that these programs did or did not exist at a particular site.

[2]One report was generated for each site. Twenty six site reports were reviewed. Some sites are multi-unit, and also may have completely different reactor types. Differences were sometimes noted between the maintenance programs of one unit compared to another at the same site.