AEOD/S804B

APPLICATION OF THE NPRDS FOR MAINTENANCE EFFECTIVENESS MONITORING

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NOTE: Appendixes A and B to this report contain plant-specific data from the Nuclear Reliability Data System (NPRDS). Therefore, they must be treated as containing PROPRIETARY commercial nuclear power plant information.

EXECUTIVE SUMMARY

On November 28, 1988, the Commission issued a proposed rule on ''Ensuring the Effectiveness of Maintenance Programs for Nuclear Power Plants,'' 10 CFR 50.65. The proposed rule would require licensees to formalize their maintenance programs in accordance with the definition in the rule, and to monitor the effectiveness of their programs. Specifically, the rule would require licensees to:

> *. . . regularly assess the effectiveness of this maintenance program, and based upon this assessment, make improvements as appropriate.*

Operating characteristics such as consistently high availability, or low equipment-caused forced outage rates over several operating cycles are indicators of good maintenance effectiveness. However, plant material condition can degrade significantly before these indicators provide identification of degraded maintenance performance. A more timely indication of the effectiveness of maintenance is needed.

To support the monitoring provision of the proposed rule, the NRC's Office for Analysis and Evaluation of Operational Data (AEOD) conducted maintenance performance indicator developmental activities and documented their results in AEOD/S804A *Preliminary Results of the Trial Program on Maintenance Performance Indicators*, which was transmitted to the Commission by SECY 88-289 on October 7, 1988. That report concluded that indicators which are based upon actual component reliability and failure history provide the best measure of maintenance effectiveness. It recommended that:

> *Licensees should be strongly encouraged to utilize an industry-wide component failure reporting system, e.g., NPRDS, as a basic element of the maintenance effectiveness monitoring activity that is to be required by the rule.*

This report, AEOD/S804B, demonstrates the utility of the Nuclear Plant Reliability Data System (NPRDS) to provide useful maintenance effectiveness monitoring information. It documents the development of an indicator that is based upon the component failure reports submitted to the NPRDS, and demonstrates that the monitored indicator reflects maintenance effectiveness.

Demonstrating the validity of the candidate indicator required that the indicator be based on a reasonably complete, consistent set of NPRDS data. In order to ensure that the data would satisfy these criteria, this study considered only major components in systems which have historically been significant contributors to forced outages. Failures of this equipment were considered most likely to be reported to the NPRDS regardless of a plant's NPRDS reporting consistency or the aggressiveness of its operations personnel in detecting failures. Using this data, an indicator of maintenance effectiveness was then constructed that monitors *increases* in the failure rates within a system, and provides a signal when an increase exceeds a specified value. This yields a measure of the changes in the effectiveness of maintenance on a system basis. To obtain a measure of a plant's level of maintenance effectiveness, the number of indications or signals is tallied across a number of systems. This tally is but one indication of the effectiveness of a plant's maintenance program. Other items, such as additional indicators, systems analyses, and inspections, are needed to obtain a complete picture of the absolute level of the effectiveness of maintenance at any plant.

The validation as to whether the candidate indicator reflected maintenance effectiveness was based upon deterministic engineering analyses and empirical methods. Engineering studies of NPRDS failure records for such components have revealed that differences in maintenance practices among the plants caused differences in failure rates. Further, root cause analyses of the failures comprising the indicator revealed maintenance effectiveness as the major cause. Figure A illustrates this part of the validation process. Finally, empirically, it was shown that the indicator correlates reasonably well with other information regarding maintenance problems derived from Licensee Event Reports (LERs).

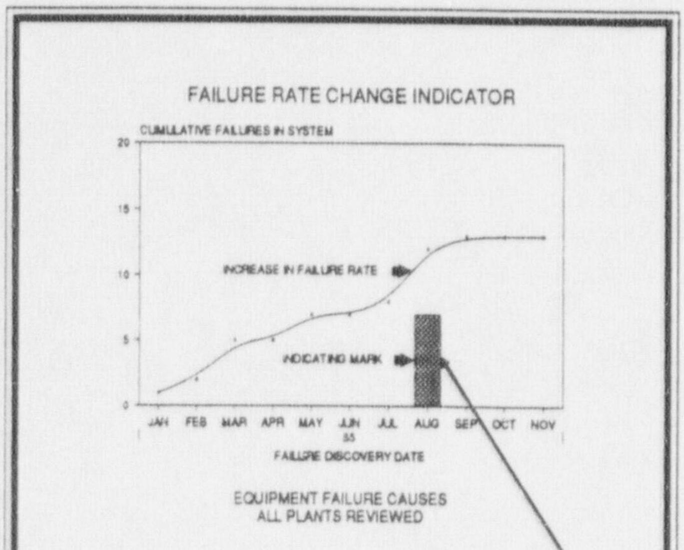

Figure A

The usefulness of the candidate indicator, and any other indicator developed based upon the component failure reports submitted to the NPRDS, relies to a large degree on the quality and completeness of NPRDS reporting by licensees. Since such reporting is voluntary and subject to individual utility priorities and commitments, some limitations are inherent in the utilization of NPRDS failure reports for maintenance effectiveness trending.

This report documents that a practical and useful maintenance performance indicator was developed using NPRDS data. The ability of the candidate indicator to reflect maintenance effectiveness was confirmed. The effect of non-uniform NPRDS reporting was shown to be acceptably minimized through the use of a standard subset of equipment that is important to plant operations.

The value of the candidate indicator was confirmed through independent data derived from maintenance-caused events reported in LERs, correlations with other studies, and correlations with the findings from maintenance effectiveness team inspections. While the focus of this report is on the use of NPRDS to monitor maintenance effectiveness, the mutually reinforcing correlation between LER-based data and the NPRDS-based indicator points to the prospect of an additional maintenance indicator. The LER-based data used in this correlation resulted from the ongoing performance indicator development effort aimed to demonstrate the usefulness of cause codes, one of which is maintenance. Further development of this maintenance cause code from LERs is being pursued for use in monitoring maintenance effectiveness.

Although the methodology used in this study was developed using data for 28 BWRs, it should prove equally valid for other plant designs. Other valid indicators may be developed from this data but the candidate indicator developed in this study serves as a suitable basis for describing a maintenance effectiveness tracking method which is acceptable to the staff in the forthcoming Maintenance Rule regulatory guide.

In order for the NRC staff to use the candidate indicator on an industry-wide cost-effective basis, further development is necessary to more efficiently extract the indicator from the NPRDS system and to display it in a manner which permits individual as well as generic comparisons. The staff continues to give further development efforts high priority and will share the results of its activities with industry.

APPLICATION OF THE NPRDS FOR MAINTENANCE EFFECTIVENESS MONITORING

INTRODUCTION

The Office for Analysis and Evaluation of Operational Data (AEOD) recently issued AEOD/S804A, "Preliminary Results of the Trial Program on Maintenance Performance Indicators" (Ref. 1). A number of candidate maintenance performance indicators were analyzed, including process indicators such as corrective maintenance backlog, and equipment performance-based indicators such as rework and frequency of failure. A major conclusion of this study was:

> *Indicators that are based upon actual component reliability and failure history provide the best measure of maintenance effectiveness....*

At the most fundamental level, this translates into tracking component performance through the construction of component failure histories. Tracking equipment performance is also generally accepted as a way of improving maintenance. AEOD/S804A noted, however, that licensees generally were not using such data to assess maintenance effectiveness. Independently, as shown in the following findings, recent NRC maintenance inspections also found this to be the case:

> *Improvements in problem resolution remain to be demonstrated, in view of prior and recent missed opportunities to recognize and correct the root causes of plant problems. The absence of effective equipment performance trending programs appears to have contributed to such oversights.* (Ref. 2, emphasis added)

> *Work history and performance history are not integrated and repetitive failures of work on similar components cannot be*

readily identified. Therefore, root cause analysis and prompt identification and correction of problems (are) *not as effective as* (they) *could be.* (Ref. 3)

Trending of equipment failures - the inspection team observed examples of failures to adequately assess and trend equipment failure data. . . . In addition to the lack of an adequate trending activity, this weakness in providing feedback to the PM (i.e., preventive maintenance) *program also stems from incomplete maintenance and equipment history records.* (Ref. 4)

AEOD/S804A also noted that most plants have a maintenance work request tracking system but that such systems do not lend themselves to the ready identification and tracking of individual component failures. Consequently, it was concluded that the Nuclear Plant Reliability Data System (NPRDS) (Ref. 5) was the best available source for component failure data. This conclusion was independently observed during one of the previously cited inspections (Ref. 3). The inspection report noted that:

Repetitive failures of work on similar components cannot be readily identified by using CHAMPS (i.e., the plant's maintenance tracking system) . . . *NPRDS is generally used, when requested, for failure determination.*

Since the NPRDS is such a valuable resource, it must continue to maintain a high quality of component failure data. To confirm that the NPRDS remains a viable source for component failure data, the NRC periodically assesses its quality. The most recent annual appraisal is provided as an attachment to this report.

Building on the findings of AEOD/S804A and the recent maintenance inspections, work continues on the development of maintenance performance indicators based on NPRDS data. This report describes the results of this work by providing a detailed example of how NPRDS failure histories for selected equipment, called outage dominating equipment (ODE), can be combined into an indicator of maintenance effectiveness. While the indicator was developed and validated based upon NPRDS data for a single reactor type, i.e., General Electric (GE) boiling water reactors (BWRs), the principles and approaches used are considered equally applicable to reactors of other designs.

The next section discusses the construction and use of the candidate indicator. Subsequent sections provide details about the process used to validate this indicator and an examination of its use as a timely indicator of equipment forced outages.

INDICATOR DEFINITION AND CONSTRUCTION

The indicator constructed in this study scans the NPRDS component failure rate data within a system and signals any increase in that rate which exceeds a predetermined threshold value. The number of these flagged failure rate increases is then tallied for all systems considered over a specified span of time to obtain a measure of the level of maintenance effectiveness at a plant. Figure 1 is an example for one plant of the component failure rate increases that were flagged for five different systems. In this example, a total of 22 failure rate increases were signaled during approximately a three-year time span. The following sections discuss in detail the definition of the indicator, the methods and reasons for the selection of the equipment and failure data used, and the construction of the indicator from that data.

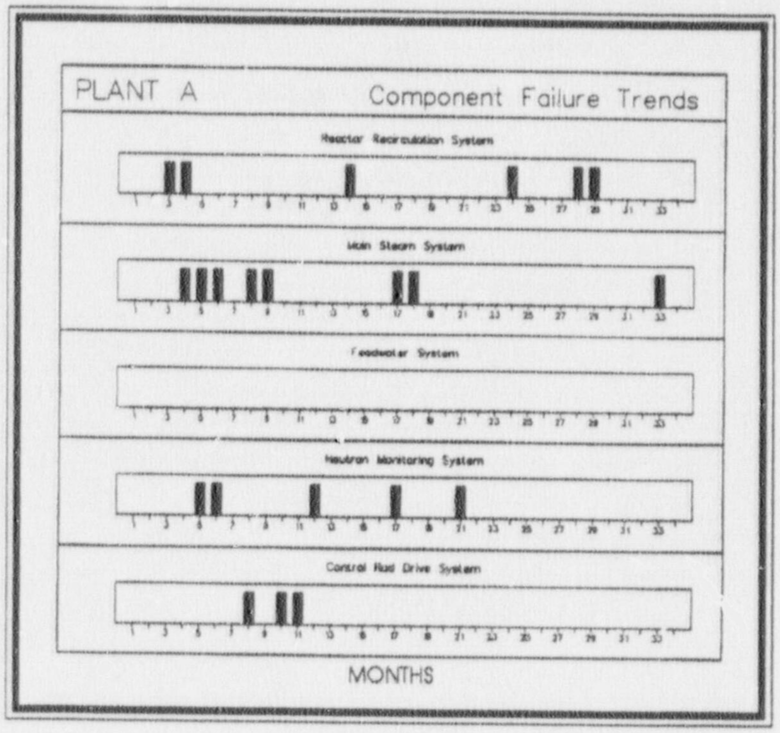

Figure 1

INDICATOR DEFINITION

Of the number of parameters which could be monitored as an indicator of maintenance effectiveness, the rate of reported component failures (i.e., failures per month) was considered to be the most definitive measure of equipment performance and the one that could be directly linked to the effectiveness of the maintenance performed on that equipment. However, this parameter is susceptible to plant-to-plant inconsistencies in failure reporting. Control of such inconsistencies, as well as data completeness, can be exercised by measuring a plant against itself. This can be done by monitoring either the deviations from an average failure rate or a change in the failure rate. This study focused on the change in the failure rate as the indicator of maintenance effectiveness.

An increase in the rate of component failures is indicative of a change in the effectiveness of maintenance. Such a change in failure rate lends itself well to trending and, consequently, may be used as a trend indicator. This may be accomplished by tallying the number of increases in the component failure rate over a given time span for a number of different systems. This tally by itself is but one indication of the effectiveness of a plant's maintenance program. Other items, such as additional indicators, systems analyses, and inspections, are needed to obtain a complete picture of the absolute level of the effectiveness of maintenance at any plant.

It should be pointed out that the methodology used to obtain the indicator grouped the failure data according to particular components in selected systems. During the course of the developmental analyses, it was found that applying the indicator at a higher level, e.g., all components together, diluted its sensitivity and resulted in relatively fewer indications than were obtained when the analysis was performed on an individual system basis. Another insight that stemmed from these analyses was that the data must be analyzed on at least a monthly basis. Viewing the failure data on a quarterly basis resulted in a loss of the fine detail and sometimes a dampening out of pronounced increases in component failure rate that were exhibited when a monthly basis was used.

INDICATOR CONSTRUCTION

In the construction of the candidate indicator, a comparative formula was developed to detect the rate of change in the failure rates of the components within a system. It was then computerized so that it would signal a component failure rate change that exceeded a predetermined value. Once the formula was computerized, it was adjusted to be sensitive to changes in the component failure rate that appeared significant based on trends observed in the historical data from 10 BWRs.

The resultant computerized indicator formula counts the number of component failures discovered during each month in a five-month span of time for each of the selected systems. Dividing the number of component failures for each of the systems in a selected time period by the number of months in the period, it then calculates the average component failure rate for each system for (a) the first three months of the five-month time span and (b) the failure rate for the last two months of the span. It then compares the two average rates and, if the rate in the last two months exceeds that of the first three months by more than a threshold value, an indicating mark is placed in the last month of the five-month span. The program then adds the next more recent month and drops the oldest month, i.e., the five-month span is shifted forward one month, and the failure rate calculations and comparison are repeated. This moving window approach has the effect of providing multiple indicating marks over successive months if an increase in failure rate is large or if it is sustained over a number of months. Thus, the indicator weights periods of time in proportion to the degree of change in the component failure rate. Figure 2 shows how an increasing failure rate trend is signaled by this method.

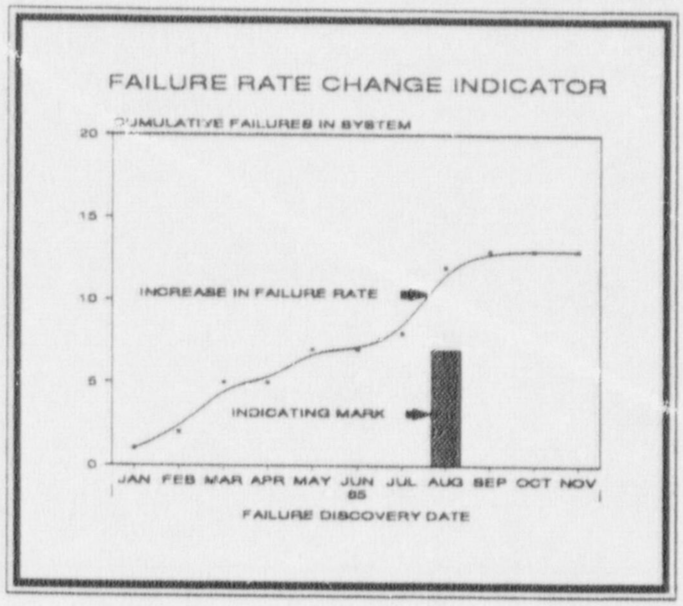

Figure 2

DATA CONSISTENCY AND COMPLETENESS

The data used in the construction and validation of the candidate NPRDS-based indicator had to satisfy two criteria:

(1) A consistent set of NPRDS data had to be obtained for each plant, and

(2) The individual plant data sets had to be reasonably complete.

Major differences in the level of NPRDS reporting from unit to unit have been observed. To accommodate the shortcomings of incomplete NPRDS reporting, a logic was applied to utilize a subgroup of the equipment failures in the NPRDS. Two factors dictated the group of equipment selected. First, during the site visits of the trial program documented in AEOD/S804A, it was noted that the operating crew played a major role in maintenance work request (MWR) generation during plant operation. The NPRDS failure reports are dependent upon MWR generation and are therefore sensitive to the aggressiveness of the operating crew in the complete and timely identification of equipment problems. To minimize the effects that could be attributed to variations among plants, the data analyzed was limited to failures of major components in systems that support power operation. In cases where a plant was shut down, if it were to start up without having repaired the failed equipment, the plant would be operating with a degraded system that could eventually have an adverse impact on power operation. Failures of this equipment are much more likely to be identified for repair in a timely manner, thereby minimizing the potential impact of the variations in the identification of failures.

The second factor that was used to assure reasonable completeness of the data set was information obtained from the NPRDS coordinators. Generally, the NPRDS coordinators are the individuals that produce the NPRDS reports based upon the maintenance work request input. During the trial program reactor site visits, it was found that, although the absolute reporting rate may vary widely from unit to unit, the NPRDS coordinators generally report the *important failures.* Important failures, in their view, were those that could influence plant operation to such a degree that a plant outage could occur at their plant or another plant.

Considering these two factors, the candidate maintenance indicator was based on NPRDS-reported failures from the set of equipment that historically has caused equipment forced outages. This data set represented reasonably complete component failure information for a reasonable scope of equipment. Variations from plant to plant due to different NPRDS reporting philosophies were further lessened by using only those types of component failures that the NPRDS *Reporting Procedures Manual* (Ref. 6) requires to be reported (i.e., immediate and degraded failures). Incipient failures were not considered.

SCOPE

The scope of the analysis used to construct the candidate indicator was limited to a specific subset of operating plants for a specific time period due to staff resource constraints. The subset studied was further restricted to only those plants with nuclear steam supply systems (NSSS) designed by GE that were operational between January 1, 1985 and March 31, 1988. Further, the equipment considered was restricted to those BWR systems and components which historically have been the dominant contributors to forced outages, i.e., ODE systems and components, that are within the NPRDS reportability scope. While this study was restricted to only one plant design, the methodology developed should be equally applicable to all plant designs.

The set of components in BWR ODE systems that was selected and analyzed was based on a compilation performed by the S. M. Stoller Corporation for the EPRI (Ref. 7). This compilation used the OPEC-2 database (Ref. 8) to determine and rank the contributing factors to plant unavailability down to the component level. A number of the dominant contributors to plant unavailability that were listed were related to either personnel or planned outages such as refueling. These contributors were not considered. Equipment was also eliminated that was structural, such as BWR recirculation piping, or outside the current reportability scope of the NPRDS. Table 1 lists the systems and components that were selected for this study.

TABLE 1: BWR ODE SYSTEMS AND COMPONENTS

SYSTEM	COMPONENT DESCRIPTION
Control Rod Drive	Control Rod Mechanism
	Control Rod
	Control Rod Drive Flow Control Valve
	Control Rod Drive Flow Control Valve Operator
	Control Rod Drive Supply Pump
	Control Rod Drive Supply Pump Motor
	Control Rod Drive Supply Pump Motor Circuit Breaker
Feedwater	Feedwater High Pressure Heater
	Feedwater Pump
	Feedwater Pump Motor
	Feedwater Pump Motor Circuit Breaker
	Feedwater Pump Turbine
	Feedwater Pump Turbine Governor
Main Steam	Main Steam Automatic Depressurization Safety Valve
	Main Steam Automatic Depressurization Safety Valve Operator
	Main Steam Containment Isolation Valve
	Main Steam Containment Isolation Valve Operator
	Main Steam Containment Isolation Valve Operator Circuit Breaker
	Main Steam Safety/Automatic Depressurization Discharge Pipe Vacuum Breaker
	Main Steam Safety Valve
Neutron Monitoring	Instrumentation, Bistable/Switch
	Instrumentation, Indicators/Recorders
	Instrumentation, Transmitter/Primary Detector/Element
Reactor Recirculation	Instrumentation, Bistable/Switch
	Instrumentation, Indicators/Recorders
	Instrumentation, Transmitter/Primary Detector/Element
	Reactor Recirculation Pump
	Reactor Recirculation Pump Motor
	Reactor Recirculation Pump Motor Circuit Breaker
	Reactor Recirculation Pump Discharge Valve
	Reactor Recirculation Pump Discharge Valve Operator
	Reactor Recirculation Pump Discharge Valve Operator Circuit Breaker
	Reactor Recirculation Pump Suction Valve
	Reactor Recirculation Pump Suction Valve Operator
	Reactor Recirculation Pump Suction Valve Operator Circuit Breaker
	Reactor Recirculation Pump Motor Generator Set Generator
	Reactor Recirculation Pump Motor Generator Set Coupling
	Reactor Recirculation Pump Motor Generator Set Motor
	Reactor Recirculation Pump Motor Generator Set Motor Circuit Breaker

The equipment listed in Table 1 is not an all inclusive list. Based on the results of this study, some changes are in order. For example, the BWR feedwater regulating valve and its operator were not identified in the Stoller report as dominant contributors to BWR forced outages. However, from the number of reported failures of these components found in the NPRDS during this study, these components were significant contributors to equipment forced outages at some of the plants considered. Consequently, they should be added to the list of key outage-causing equipment. Further, the NPRDS currently does not include certain balance-of-plant (BOP) systems and components that have historically been significant contributors to plant outages, such as the turbine-generator and associated support systems, the condenser, the circulating water system, non-nuclear portions of the service water and closed cooling water systems, the instrument air system, and the service air system. At the most recent meeting of the NPRDS Users Group (NUG) held in December 1988, the NUG recommended to the Institute of Nuclear Power Operations (INPO) that the reportability scope of the NPRDS be expanded to include the main turbine, the main generator, and the condenser. This action marks the first official step in the NPRDS scope expansion process.

As an independent check on the selected outage dominating systems and components, published results were reviewed of a study of plant availability that was done by the North American Electric Reliability Council (NERC) using their NERC-GADS database (Ref. 9). This review confirmed the basis used for selecting the equipment listed in Table 1.

As a result of queries of the NPRDS based on these systems and components, it was found that 8 of the 37 operating GE BWRs had too little data to analyze because of either limited commercial operating history or, in some cases, due to extended shutdowns during the study period. In addition, Big Rock Point does not report to the NPRDS because of its unique design characteristics. Thus, the validation was based on NPRDS failure data from 28 operating GE BWRs.

The use of the indicator model and computerized algorithm developed during this study results in considerable time savings in the calculation of the candidate indicator for the number of plants analyzed. However, this process still requires the manual downloading of large amounts of component failure data from the NPRDS. Further manipulation of the downloaded data is required to prepare the input for the algorithm. These two efforts are time-consuming and labor-intensive. The desirability of trending component failure rate has been recognized by NPRDS users. The current NPRDS user software has the capability to trend failure rates in an automated way. Efforts have been initiated to see if expansion or modification of this software is possible so that it could provide the candidate indicator.

The following section of this report documents the validation method that was used to confirm the relationship of the candidate NPRDS-based indicator to the Commission's definition of maintenance effectiveness.

VALIDATION

Validation of the candidate indicator was accomplished through two tasks. The first task consisted of a root cause analysis of those component failure rate increases identified by the indicator. This analysis was done to determine if the indicator is a direct or nearly direct measure of maintenance effectiveness. In the second task, the candidate indicator was compared statistically with another measure of maintenance effectiveness that is currently under development, namely, the frequency of maintenance-caused reportable events documented in Licensee Event Reports (LERs) submitted in accordance with 10 CFR 50.73 (Ref. 10). While both the NPRDS- and the LER-based indicators are the subject of validation, a positive correlation between indicators based on data from different sources would be mutually reinforcing.

Applying the computerized algorithm technique to the NPRDS component failure data for the three year period considered resulted in between 0 and 8 indications for each of the ODE systems for a given plant, with the average number of indications per system per plant varying between 2 and 3. About half of the indications were due to failures discovered during power operation and half were due to failures discovered during an outage. Forty of the component failure rate increases flagged by the algorithm were examined by AEOD contractors at the Idaho National Engineering Laboratory (INEL) to establish the relationship between the component failure rate increases and maintenance effectiveness. This involved reviewing the NPRDS descriptions of the 500 component failures which contributed to the 40 failure rate increases and assigning the cause of each failure to one of five distinct categories:

(1) **Ineffective Maintenance** - Failures experienced while conducting, or as a consequence of, maintenance, upkeep, repair, surveillance, testing, and calibration of plant equipment. Examples include personnel errors of omission and commission by maintenance staff, procedure problems resulting in inadequate/improper maintenance, problems traceable to maintenance program administrative control, and equipment failures due to improper previous repair.

(2) **Random** - Failures of this type usually occur in electronic equipment and are rare in operating equipment. As the term implies, there is no pattern associated with the failure and, therefore, this type of failure would not be expected to be a recurring problem.

(3) **Design/Installation/Construction** - Failures experienced while performing, or as a consequence of, design, fabrication, construction, and installation of equipment, systems, and structures. Examples include personnel errors of omission and commission, procedure problems resulting in inade-

quate or improper design or installation, and problems traceable to design or construction program administrative control.

(4) **Normal Aging/Wearout/End-of-Life** - Failures caused by a component or system reaching its end-of-life by normal aging or wearout.

(5) **Unknown** - insufficient information was provided in the failure narratives to determine the root cause of the failure.

As shown in Figure 3, it was found that over three-fourths of the failures involved maintenance ineffectiveness. On a plant-specific basis, the contribution ascribed to ineffective maintenance ranged from about 25 percent to 100 percent.

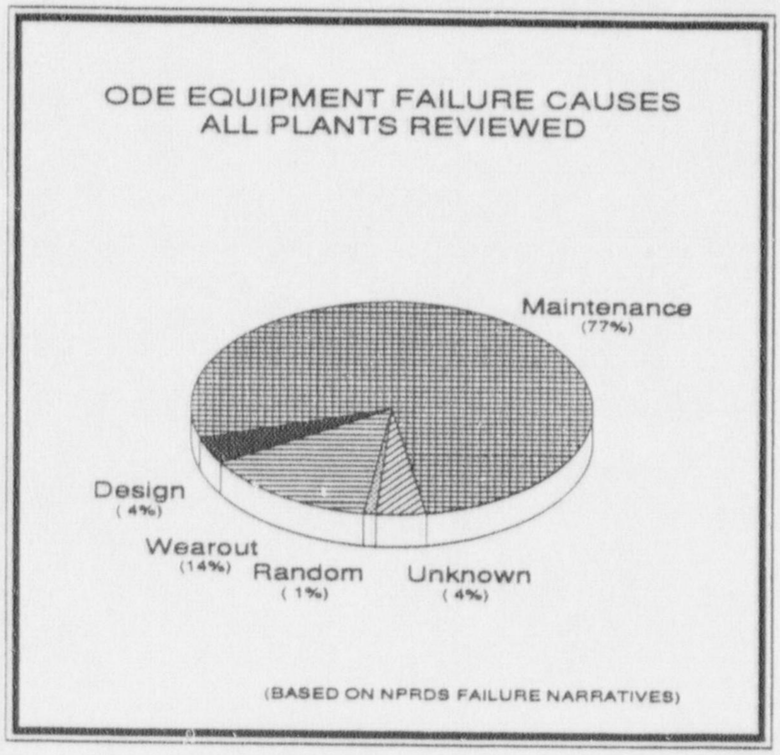

Figure 3

The strong relationship of these failures to maintenance ineffectiveness has been confirmed in other studies. For example, a trends and patterns analysis was completed by AEOD of NPRDS failure data for main feedwater (MFW) flow control valves, MFW flow control bypass valves, and MFW pumps in U.S. commercial pressurized water reactors (PWRs) (Refs. 11, 12). The primary finding of this analysis was that differences among plants that could be traced to differences in maintenance practices had a greater influence on the failure rate of these components than any of the component design features studied. This result was independently obtained, but echoed the results of a 1980 Electric Power Research Institute (EPRI) study of MFW pump performance (Ref. 13). The EPRI report concluded that the ultimate performance of a major component such as a pump is affected more by how it is maintained than by the selection of a specific pump manufacturer. AEOD has also performed a trends and patterns analysis of main steam isolation valve (MSIV) failures at both PWRs and BWRs (Ref. 14). Based on NPRDS data, the major finding of this analysis was that proper maintenance was a dominant means for minimizing MSIV problems at both PWRs and BWRs.

The second validation task determined if positive correlations existed in cases where plants with high frequencies of operating events which can be ascribed to maintenance deficiencies also exhibit a high degree of ODE indication, and whether plants with moderate and low frequencies of maintenance-related events exhibit moderate and low degrees of ODE indication, respectively. The events used in this comparison were those reported to the NRC in LERs. A correlation was found between the candidate indicator and the LER-based maintenance-caused event frequency. This correlation reinforces the conclusion that NPRDS can support a useful maintenance effectiveness indicator. A detailed explanation follows.

Using the historical LER database in the Sequence Coding and Search System (SCSS) (Ref. 15), the Nuclear Operation and Analysis Center (NOAC) of the Oak Ridge National Laboratory (ORNL) developed a technique to classify the causes of the events reported in LERs. One of these causes is maintenance. The classification technique uses specific search algorithms to produce the same results as manual cause coding of LERs by experienced engineers. Each event can be categorized by one or more causes.

The maintenance cause category covers the entire range of programmatic deficiencies related to maintenance, surveillance, testing, and calibration. These deficiencies are deemed attributable to poor maintenance practices or errors made by maintenance personnel. The deficiencies include:

(1) **Maintenance personnel errors** - Personnel errors associated with the performance of surveillance, testing, calibration, or radiation protection activities; and

(2) **Poor maintenance practices** - Equipment failures that are strongly indicative of maintenance problems such as improper lubrication, corrosion due to boric acid precipitation, short circuits, and improper prior repairs.

To eliminate the effects of the startup of NPRDS reporting on the candidate indicator count, this analysis was applied to those BWRs which began commercial operation prior to January 1, 1985. Hence, the number of BWRs considered was reduced from the 28 used in the first part of the candidate indicator validation to 23. The mean number of maintenance-related events occurring per month during the period of interest at each of these 23 BWRs was calculated based on the number of events in the SCSS LER database that involved maintenance deficiencies (i.e., maintenance-related events). This mean maintenance-related event frequency provides some comparative measure of maintenance performance. That is, plants with the highest mean frequency of maintenance-related events seem to experience the greatest difficulty with their maintenance programs compared with other plants. Using similar techniques, the candidate indicator was also calculated.

Using a linear correlation analysis, the degree of association between the candidate indicator and the mean maintenance event frequency for the 23 BWRs was then examined. The analysis calculated a correlation coefficient between the candidate indicator and the mean maintenance-related event frequency of 0.6. (A correlation coefficient of zero (0) indicates there is no relationship between the variables. When there is perfect correlation and the variables vary in the same direction, the coefficient is 1.0 (positive correlation). When there is perfect correlation but the variables vary in opposite directions, the coefficient is -1.0 (negative correlation). The correlation coefficient can vary between the extremes of -1.0 and 1.0 to indicate some intermediate degree of correlation). This positive correlation was statistically significant at the 0.01 level, indicating that the correlation was not due to random fluctuations in the data. Figure 4 shows how the two variables trend in the same direction. These results illustrate that the indicator correlated acceptably well with LER-based data. Thus, the second part of the validation process was satisfied.

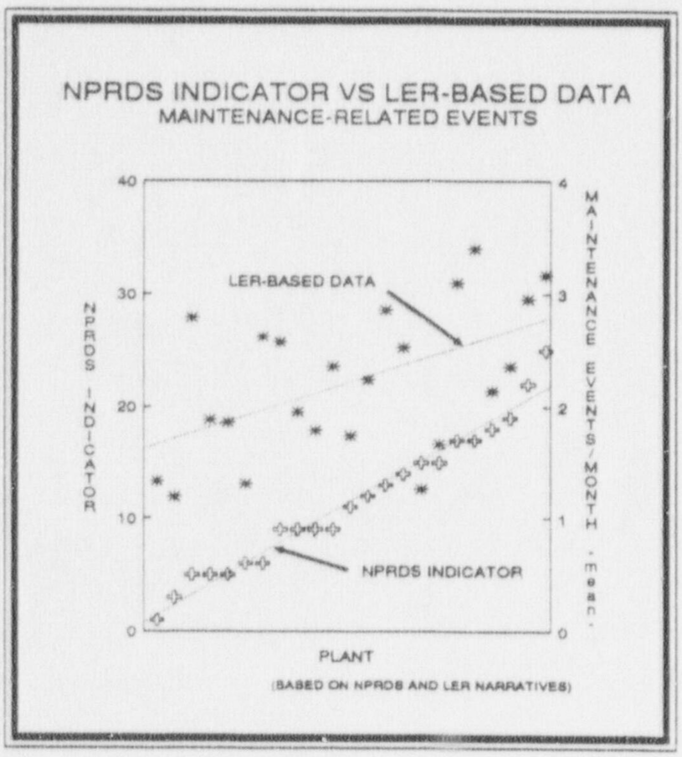

Figure 4

The correlation between the NPRDS-based candidate indicator and the LER-based data, when averaged over a long period of time, is not entirely unexpected since the NPRDS failures were shown to result primarily from maintenance ineffectiveness, and the same finding was made for failures found in LERs in NUREG-1212, the staff's trend and pattern analysis of industry maintenance (Ref. 16). The indicated strength of the correlation is quantitative confirmation of the general relationship of these two sources for measuring maintenance effectiveness. The correlation reinforces the potential value of cause codes as an additional source of information for monitoring maintenance effectiveness.

In the construction and validation of the candidate indicator, all failures were used, including those discovered during power operation and those discovered during shutdown. No distinction was made regarding the mode of operation since all of the events were actual failures and not incipient conditions. Further, the failures most likely occurred during operation, although the discovery of some of the failures could not occur until the plants were shut down. Overall, about half of the failures were discovered during operation and half were discovered during shutdown. Likewise, the failure rate increases that were flagged by the candidate indicator were due to failures that were discovered approximately equally between operation and shutdown. In both operation and shutdown, the validation indicated that failure increases showed evidence of ineffective maintenance. An aggressive preventive maintenance program would seek to identify and correct problems prior to the occurrence of actual failures such as these.

Thus, tracking all reported failures regardless of the plant operational status when the failures were discovered showed merit for indicating maintenance effectiveness. In addition, the use of failures discovered during plant shutdowns will allow gauging of the general condition of equipment entering the outage and the potential for ineffective corrective maintenance during an outage. The quality of the maintenance during an outage sets the tone for operation in the next cycle. The next section discusses a number of situations where increased failure rates due to failures discovered in an outage preceded an equipment forced outage experienced soon after restart.

RELATIONSHIP WITH EQUIPMENT FORCED OUTAGES

Because of the nature of the equipment whose historical data was used in the construction and validation of the candidate indicator, it is a logical hypothesis that there may be a relation between the indicator and the occurrence of equipment forced outages (EFOs). In this study, increases in the component failure rate for a given system are viewed as indicative of the general condition of the system. This analysis postulated an increased chance of an EFO occurring, given an observed increase in the failure rate. The usefulness of the candidate indicator would be enhanced if it provides a more timely indication of the potential for an EFO. This analysis examined the operational experience of the 28 plants in detail. The results for the individual plants are contained in the proprietary Appendix A of this report.

This analysis examined historical data that combined NPRDS failure information with forced outage information from NUREG-0020 *Licensed Operating Reactors Status Summary Report* (Ref. 17). The objective of this effort was to see whether an increase in the rate of reported system component failures preceded an EFO involving that same system. Although this seemed like a reasonable expectation, there are a number of reasons why an increase in the system component failure rate indicated by the set of data analyzed might not result in a forced outage. These include:

(1) The redundancy of the equipment design in each plant may be such that a specific system can tolerate a number of failures without the plant being required to shut down;

(2) An aggressive maintenance program may have discovered and fixed the problem equipment; and

(3) A single component failure can result in an EFO with no previous warning.

Therefore, it was recognized that the tie between the candidate indicator and EFOs may not be very strong.

To perform this analysis, component failure records for each of the ODE systems were obtained from the NPRDS (see proprietary Appendix B) and a listing of all the EFOs that were related to the ODE systems was extracted from NUREG-0020 (see Appendix C). The forced outage and equipment failure data were combined and arranged chronologically for each plant. In this manner, chronologies were assembled from approximately 3,000 component failures and 200 EFOs involving selected equipment in the reactor recirculation, neutron monitoring, control rod drive, feedwater, and main steam systems at the 28 BWRs. The trend in the rate of component failures within each system was examined using plots of cumulative failures as a function of time (months) on which were superimposed the historical EFOs and the operational history of the plant (i.e., all planned and unplanned outage periods).

Recognizing the limitations just listed, the analysis provided some positive results. Ten of the 28 plants evaluated experienced at least one EFO over the three-year period studied which was preceded by an increase in the failure rate of the components within the system that was associated with the forced outage. The lead times observed for the failure rate increase prior to an EFO generally ranged from two to six months. While these results indicate that there may be a relationship between the candidate indicator and EFOs, this relationship is not very strong.

In general for all of the plants considered, the best results were found for equipment in the reactor recirculation, feedwater, and main steam systems. Both the control rod drive and neutron monitoring systems experienced large numbers of failures, but few EFOs. Each of these two systems is composed of highly redundant components and has a capacity to absorb failures up to the limits imposed by technical specifications. These systems/components did not play a major role in this plant analysis. However, the rate of accumulation of these kinds of failures coming out of a refueling outage could be a measure of the effectiveness of the maintenance performed in the outage.

The current scope limitations of the NPRDS ruled out examining the failure experience for systems such as the main turbine and the main generator which dominated the EFO experience at several plants. This factor impacted the number of plants for which results could be demonstrated. Another limitation was that incipient failures are reported voluntarily to the NPRDS. Because of this, such failures were not used in this analysis to ensure that the results would not depend on these failures and, consequently, be invalidated if licensees had modified their reporting practices during the study time period.

Given these limitations, from the results for some specific plants, the candidate indicator appeared to have some limited potential in providng a warning signal prior to an associated EFO. However, as anticipated, the results did not show an overall statistically strong relationship between the candidate indicator and EFOs. Nevertheless, it appears that the candidate indicator performed as expected.

FINDINGS AND CONCLUSIONS

FINDINGS

The major findings of this study are:

(1) Based on a review of the individual failures in the NPRDS, increased component failure rates within a system are generally associated with maintenance effectiveness;

(2) Detailed engineering studies that employed both statistical and deterministic analyses have shown a nexus between ineffective maintenance and NPRDS-reported failures of ODE equipment, i.e., feedwater regulating valves, main feedwater pumps, and MSIVs;

(3) An equipment forced outage due to a failure of a specific system was sometimes preceded by an increased rate of failure of equipment in that system;

(4) The frequency of maintenance problems connected with reportable events showed a positive correlation with the magnitude of the candidate indicator for the period analyzed; and

(5) Implementation of the candidate indicator by the NRC staff on an industry-wide basis would be labor intensive. Consequently, more efficient data techniques need to be developed.

CONCLUSIONS

(1) A practical and useful maintenance performance indicator was developed using NPRDS data. This indicator can serve as a suitable basis for describing a maintenance effectiveness tracking method which is acceptable to the staff in the forthcoming Maintenance Rule regulatory guide. Other indicators could be developed from the NPRDS data.

(2) The ability of the candidate indicator and the NPRDS data to reflect maintenance effectiveness was confirmed.

(3) The effect of non-uniform NPRDS reporting can be acceptably minimized through the use of a standard subset of equipment that is important to plant operations.

(4) The value of the candidate indicator was confirmed through:

- Root cause analysis;
- Independent data derived from LER-reported, maintenance-caused events;
- Correlations with other studies; and
- Correlations with the findings from maintenance effectiveness team inspections.

While the focus of this report is on the use of NPRDS to monitor maintenance effectiveness, the mutually reinforcing correlation between LER-based data and the NPRDS-based indicator points to the prospect of an additional maintenance indicator. The LER-based data used in this correlation resulted from the ongoing performance indicator development effort aimed to demonstrate the usefulness of cause codes, one of which is maintenance. Further development of this maintenance cause code from LERs is being pursued for use in monitoring maintenance effectiveness.

(5) Although the methodology used in this study was developed using data for 28 BWRs, it should prove equally valid for other plant designs.

(6) For cost-effective NRC staff use of the candidate indicator on an industry-wide basis, further development is necessary to more efficiently extract the indicator data from the NPRDS and to display it in a manner which permits individual as well as generic comparisons. These efforts will receive high staff priority and the results of these activities will be shared with industry.

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