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# TRIAL APPLICATION OF RELIABILITY TECHNOLOGY TO EMERGENCY DIESEL GENERATORS AT THE TROJAN NUCLEAR POWER PLANT*

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ABSTRACT

In this paper, a trial application of reliability technology to the emergency diesel generator system at the Trojan Nuclear Power Plant is presented. An approach for formulating a reliability program plan for this system is being developed. The trial application has shown that a reliability program process, using risk- and reliability-based techniques, can be interwoven into current plant operational activities to help in controlling, analyzing, and predicting faults that can challenge safety systems. With the cooperation of the utility, Portland General Electric Co., this reliability program can eventually be implemented at Trojan to track its effectiveness.

## I. INTRODUCTION

### a. Background

Although most of the TMI and Salem corrective measures have now been implemented, new operational events nevertheless keep happening, for example, the recent events at Davis Besse, San Onofre, and Rancho Seco. One possible reason is that these corrective measures were largely prescriptive to correct identified problems and not life-cycle oriented to prevent future problems. One approach for preventing operational safety problems in the nuclear industry, that was suggested after the TMI accident and the Salem automatic-trip failures, is to make more use of reliability engineering techniques that have proved useful in other industries. Organizations such as NRC, DOE, EPRI, and others sponsored surveys of reliability technology, and coalesced for subsequent evaluation a concept of a reliability program that appears applicable to the safety of operating reactors.[1-3] This is based on the concept that a reliability program applied to operating equipment can help to assure a low frequency of transients/faults that challenge safety systems, and a reliability program (including configuration management) applied to standby systems can help to assure safety-system availability.

In May 1985, BNL began an investigation to identify the essential tasks of a reliability program and to evaluate the effectiveness and attributes of a reliability program applicable to maintaining an acceptable level of safety during the operating lifetime of a nuclear power plant.

The technical evaluation,[4] conducted through NRC's Operational Safety Reliability Research (OSRR) Project, was based on: i) a survey of applicability of reliability technology to help resolve selected generic issues; ii) an assessment of whether a reliability program would likely have prevented abnormal occurrences; iii) visits to operating plants to learn what reliability techniques have worked for these utilities and to characterize the attributes of successful reliability programs; and iv) a trial application to the Emergency Diesel Generators (EDGs) at the Trojan plant in cooperation with Portland General Electric Company.

### b. Purpose/Scope/Summary

This paper provides a summary of how reliability technology can be applied for evaluating the effectiveness of surveillance testing on a real system. This evaluation is being accomplished through an ongoing, cooperative trial application, with Portland General Electric Company, on the EDG system at the Trojan Facility (Item iv, above). The primary focus on this phase of the study is on the operational activities, viz., periodic surveillance testing, presently conducted at the Trojan Nuclear Plant and how insights in enhancing these operational activities can be gleaned from reliability technology. Over 11 major subsystems to the EDG system were analyzed and about 300 different component types identified of which 31 were identified as critical components.

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

Results,[5] to date, show that a reliability program process,[4] using risk- and reliability-based tasks, activities, and techniques, can be interwoven within current plant operational activities to i) analyze problems that have affected system performance; ii) to forecast the onset of potential problems; and iii) to suggest actions that could eliminate their occurrence (or reoccurrence).

Several of the reliability program tasks, identified and discussed in Reference 4, were exercised in this trial application. Applicable PRA models, along with FMEAs that are tied in with the plant's operational activities were used to provide specific means for identifying and prioritizing design and operational surveillance deficiencies.

## II. METHODOLOGY

A reliability program process (tasks, activities, techniques) is utilized[4] which includes diagnosis of recurring problems, prognosis of impending problems, problem prioritization, and corrective actions needed to reduce the likelihood of both recurring/impending problems before they take effect (Figure 1). A reliability program concept is described which has the potential for implementing safety goal criteria. Performance indicator technology is explored which has the potential for providing a performance tracking tool directly relatable to core-melt frequency estimates.

For this particular application, a four-stage analysis process is presented for identifying critical components (i.e., components having various failure modes that can significantly contribute to system unavailability) and operational activities that can be used to improve component reliability. The four-stage analysis process is a systematic evolution of the following steps: 1) system analysis, 2) operational activity analysis, 3) reliability improvement analysis, and 4) reliability performance analysis (Figure 2).

Reliability block diagrams and insights from failure modes and effects analysis (FMEA) of system components were utilized to help develop a system fault tree model for analysis. This fault tree model included the loss of offsite power (LOSP) initiator, the support systems required for performing the desired system function, and portions of logic systems designed to assess the functional performance of the diesel generator system. These subsystems include: air start, combustion air supply, control, cooling, exciter, exhaust fuel supply, governor, load sequencer, lube oil, turbocharger, ventilation, and voltage regulator subsystems. A multilevel analysis was used to identify the dominant component failures at four levels: 1) the unavailability of the emergency ac power system, 2) the unavailability of one train of the emergency ac power, 3) the failure of one tandem* unit to start, and 4) the failure of one tandem unit to run (or operate) after a successful start. Quantitative analysis of the system fault tree provided dominant cutsets to identify critical components at the system and "train" levels. For each dominant cutset, recovery actions for failure modes of critical components were investigated by review of the plant's Off-Normal Instruction (ONI) procedures against the FMEAs performed for the system components. On the basis of insights gleaned from the system/train fault trees, a list of critical components was developed to focus attention on potential areas that may require remedial action.

In addition, analysis of plant experience data was used to supplement this list. The diesel generator experience data for the Trojan nuclear plant were obtained by analyzing maintenance work requests from 1983, 1984, and the first 5 months of 1985. A total of 91 maintenance records were examined[6] and each diesel generator failure was categorized by: severity, engine condition at the time of fault detection (standby or running), stress cause, repair category, and effect upon the system (immediate or long term). The severity of a diesel generator failure was ranked according to three degrees: catastrophic, degraded, and incipient. The results[5-6] indicate that catastrophic failures are largely caused by failures in electrical components; degraded and incipient failures are dominated by faults in mechanical components.

Although there have been few catastrophic failures of the diesel generator system or its piece parts at the Trojan nuclear plant, plant-specific data for dominant failures were applied in the quantification process to provide more realistic results in terms of the information base of generated cutsets. The incorporation of plant-specific data in fault tree quantification results in the identification of a realistic mix of "active" and "passive" components that constitute the prioritized list of critical components for focusing on problem areas.

The list of critical components that contribute to system unavailability, generated on the basis of fault tree analysis, was then integrated with the list of components which were identified on the basis of plant-experience data that indicated catastrophic and degraded failures of the system. This integrated set of critical components are listed in Table 1. This list was subsequently used to systematically analyze the adequacy of current operational

*The Trojan plant has two identical diesel generator units. Each diesel generator unit consists of two fast starting, tandem-mounted diesel engines, a generator, and a number of support systems.

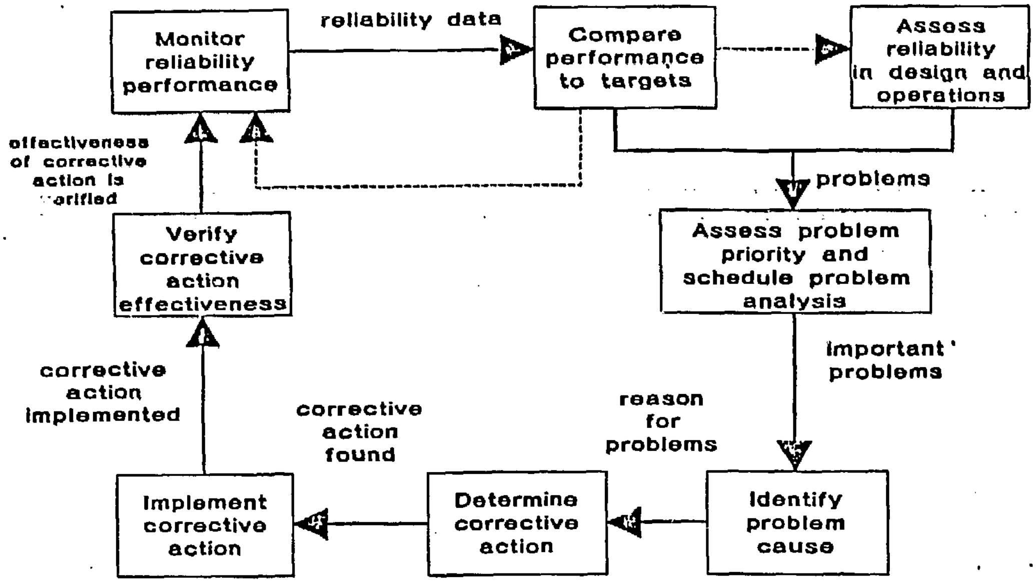


Figure 1. Reliability Program Process

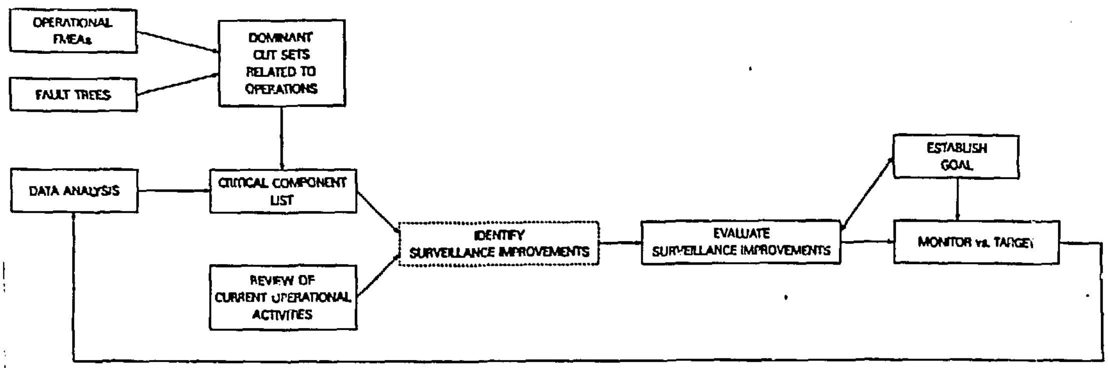


Figure 2. Reliability Elements to Improve Surveillance Effectiveness

Table 1 Integrated Lists of Critical Components

1. Field flashing circuit
2. Generator excitation circuit
3. Voltage regulator (automatic/manual)
4. Diesel generator "Start/Run" control circuit
5. Circuit breaker 152-108 closing coil
6. Generator lockout relay (186-1D1, 186-1D2)
7. Generator stator winding
8. Service water/jacket water heater exchanger
9. Service water motor-operated valve
10. Main lube oil pump strainer
11. Lube oil scavenging pump strainer
12. Air compressor unloader
13. Jacket water thermostatic control valve
14. Engine main bearings
15. Camshaft/timing gear
16. Generator bearing/coupling
17. Generator slip-rings and brushes
18. Crankshaft-to-piston connecting rod
19. Lube oil scavenging pump
20. Main lube oil pump
21. Engine jacket water pump
22. Crankshaft
23. Fuel oil day tank outlet valve
24. Lube oil cooler
25. Turbocharger aftercooler
26. Engine crankcase pressure instrument
27. Expansion tank
28. Annunciator
29. Engine speed control switch
30. Fuel oil transfer pump breaker
31. Voltage regulator selector switch

reliability activities at Trojan and to identify areas where component reliability can be potentially improved. If the critical components that were identified were not considered in present operational reliability activities, viz., walk through inspections and periodic operational tests (POTs), then they would likely be candidates for improved surveillance including visual inspection and condition monitoring. Table 2 shows the prioritized components that are presently monitored by the various plant operational activities.

Operational activities that can improve component reliability through rapid detection of failures, timely and proper corrective maintenance, and effective preventive maintenance and condition monitoring schemes were identified. For possibly detecting failures rapidly, the types of component failures that could be detectable during plant "walk throughs," and through the adequacy and efficacy of periodic testing were investigated. Detectability of failure or degradation of equipment monitored by existing system specific alarms and instrumentation in different modes of system operation was also examined. Investigations into timely and proper corrective maintenance activities focused on the controlling measures that could assure proper maintenance procedures are performed.

The effectiveness of detecting component degradation on the basis of parameters measured during periodic operational testing and thereby triggering preventive maintenance was examined through application of multivariate statistical techniques. For example, a review of the plant's maintenance records and a review of Trojan's response to Generic Letter 84-15 indicated that diesel generator system trips due to crankcase lube oil pressure being out of limits was a recurring problem. A condition monitoring scheme was used to investigate: 1) if there were any prior indications to alert the occurrence of crankcase lube oil pressure being out of limit, or 2) if there was any evidence of the cause of this abnormality on the basis of records of other physical parameters. In this condition monitoring scheme, multivariate statistical techniques, described in References 4 and 5, were utilized to analyze the recorded data sheets associated with periodic operational tests (POT), specifically POT-12-1. Although analysis did not substantially show any correlation of statistical significance amongst the recorded data, and hence was not effective in describing the root cause for the high and low crankcase pressure readings, the approach does appear promising and it is believed that a valid assessment of the root cause could have been made if mass flow measurements from the crankcase to the turbochargers were available.

Appropriate strategies for addressing problem areas in operational activities to enhance reliability at the component level were investigated. The effectiveness of recommendations that are geared towards component level reliability improvement can be quantitatively analyzed. This phase of the study is planned for the next fiscal year with the cooperation of the utility. Quantitative assessment of reliability improvement will be performed using analyses described in Reference 4. Predicted improvements can be integrated through Probabilistic Risk Assessment (PRA) methodologies to provide a measure of the reliability enhancement at the system level.

After the implementation of operational activities which could improve system reliability, the final stage in the overall process is to monitor risk and reliability performance. This stage is to identify the performance indicators that can be used to evaluate the effectiveness of operational activities in achieving reliability performance. Such performance indicators include increased subsystem or "train" availabilities and reduction in component failures. Work on risk-based performance indicators is presently under study at BNL.

Table 2. Prioritized Components Monitored by Plant Operational Activities

| Components | Operational Activities: Walk-Through Inspection | Periodic Operational Testing | Semi-Annual and Annual Maintenance |
|---|---|---|---|
| Field flashing circuit | | X | |
| Generator excitation circuit | | X | |
| Voltage regulator (automatic/manual) | | X | |
| Diesel generator "Start/Run" control circuit | | X | |
| Circuit breaker 152-108 closing coil | | X | |
| Generator lockout relay (186-1D1, 186-1D2) | X | X | |
| Generator stator winding | | X | X |
| Service water/jacket water heat exchanger | X | X | X |
| Service water motor-operated valve | | X | X |
| Main lube oil pump strainer | | X | X |
| Lube oil scavenging pump strainer | | X | X |
| Air compressor unloader | X | X | X |
| Jacket water thermostatic control valve | | X | X |
| Engine main bearings | | X | X |
| Camshaft/timing gear | | X | X |
| Generator bearing/coupling | | X | X |
| Generator slip-rings and brushes | | X | X |
| Crankshaft-to-piston connecting rod | | X | X |
| Lube oil scavenging pump | X | X | X |
| Main lube oil pump | X | X | X |
| Engine jacket water pump | X | X | X |
| Crankshaft | | X | X |
| Fuel oil day tank outlet valve | | X | X |
| Lube oil cooler | X | X | X |
| Turbocharger aftercooler | | X | X |
| Engine crankcase pressure instrument | | X | X |
| Expansion tank | X | X | X |
| Annunciator | | X | |
| Engine speed control switch | | X | |
| Fuel oil transfer pump breaker | | X | |
| Voltage regulator selector switch | | X | |

## III. RESULTS

Critical components in the emergency diesel generator system were identified using reliability techniques such as fault tree analysis, FMEA and plant-specific data analysis. Plant-specific data were analyzed from available maintenance records to identify recurrent problems during system operational experience. A generic data base was utilized for the quantitative analysis of the system fault tree model. A prioritized list of 31 critical components was obtained on the basis of these insights for addressing reliability improvement at the component level in concert with present plant operational activities. The effectiveness of current operational activities were systematically addressed in areas such as walk-through inspection, periodic operational testing and maintenance activities. Potential problem areas or blind spots involving the prioritized system components were identified. For example, critical components such as the service water motor-operated valve, mechanical governor, and fuel oil day tank outlet valve were identified for inclusion in the walk-through inspection list to detect early failure or degradation. Specific degraded or incipient failure modes identified through FMEAs include the in-leakage of jacket water into the lube oil systems. In the area of preventative maintenance, electrical components such as field flashing, generator excitation and diesel generator "start/run" control circuits were prioritized/recommended for regular visual inspection at the piece-part level to help identify the root cause of generator excitation problems. Table 3 summarizes the recommended strategies for addressing the areas of current operational activities at the Trojan nuclear plant that potentially can enhance the reliability of critical components.

Table 3. Reliability Strategies to Enhance Daily Walk-Through Inspection, Periodic Operational Testing and Preventive Maintenance

| COMPONENT | OPERATIONAL ACTIVITY/ PROCEDURE AFFECTED | STRATEGY FOR RELIABILITY IMPROVEMENT |
|---|---|---|
| Governor & associated hydraulic lines | Shift walk-through (POT 24-1) | Check for signs of oil leakage |
| Fuel lines | Shift walk-through | Inspection for signs of rupture or leakage |
| Fuel oil day tank | Shift walk-through | Verify consistency of fuel tank level indication (visual vs instrument reading) |
| †Service water motor operated valve | Shift walk-through | Verify proper indication of MOV with respect to remote indication in control room |
| *Engine lockout relays (186-1D2, 186-2D2) | Shift walk-through | Verify that relays are reset |
| †*Maintenance/Auto Selector switch (keylock switch) | Shift walk-through | Verify that selector switch is in the auto position (if no maintenance is being performed) |
| Air receiver discharge valves | Monthly test (POT 12-1) 18-month test (POT 12-2) | Provide a means to verify that no single receiver discharge valve is clogged |
| Jacket water/lube oil systems | Monthly test (POT 12-1) 18-month test (POT 12-2) | When feasible, perform chemical analysis of lube oil, jacket water for indications of metal wear, corrosion, or contamination across systems |
| Field flashing circuit, generator excitation circuit, diesel control circuit | Preventive maintenance procedure MP-7 | Perform inspection of relays for signs of sticking, contact degradation, or foreign matter |

*Alarm provided for off-normal conditions (local and remote).
†Indication provided in control room.

This trial application study has also shown that condition monitoring schemes for this system can be developed using the physical parameters recorded with instrumentation presently in place when these performance-related physical parameters are coupled with the statistical techniques such as multivariate statistical and regression analysis. The analysis shows promise in not only detecting abnormal behavior but, through statistical investigation of the correlation (or lack thereof) of the measured parameters, it may also provide the information needed for root-cause analysis. This scheme was applied to investigate abnormalities in the crankcase lube-oil pressure which showed that the technique was effective in detecting abnormalities but was not effective in providing information for root-cause analysis due to limitations of current recorded parameters.

## IV. CONCLUSIONS

A major outcome of this trial application is therefore, that feedback from operational activities can be integrated within the existing structure of an FMEA to enhance its usefulness.

Also, expanding on the traditional Reliability Centered Maintenance (RCM) framework (developed for the commercial air carrier industry) by including the dynamic integration between plant operations and maintenance could be a useful step in using a top-level RCM process for nuclear industry use.

Much can be gleaned from this particular trial application for improving the operational activities at Trojan to maintain or enhance the performance of the emergency diesel generators. Further attestment to the potential benefits of a reliability program will be realized and its effectiveness measured once the insights gained by this study are put into practice by the utility and the performance of this particular system is tracked.

However, to attest more fully to 1) the applicability of reliability technology and a reliability program process in the nuclear industry, and 2) its effectiveness in enhancing safety, more research into the techniques used throughout the course of this study is required and a wider spectrum of real applications is warranted in which the techniques proffered through the OSRR Project can be further exercised.

A major conclusion that is drawn from this research is that a reliability program process can be developed using risk- and reliability-based techniques that can be interwoven within current plant operational activities to analyze problems that have affected system performance, to forecast the onset of potential problems and to suggest actions that could eliminate their occurrence.

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