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Technical Evaluation Report

Study Group Review of Nuclear Service Diesel Generator Testing and Aging Mitigation

K. R. Hoopingarner
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March 1988

Prepared for
the U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Division of Engineering
under Contract DE-AC06-76RLO 1830
NRC/RES FIN 2911

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ABSTRACT

As part of the Nuclear Plant Aging Research (NPAR) Program, the Pacific Northwest Laboratory is performing a Diesel Generator Aging Assessment Study for the U.S. Nuclear Regulatory Commission. In the on-going NPAR Phase II of the aging study, efforts have been focused on aging mitigation and other success strategies for improving nuclear plant diesel generator operation and maintenance.

A study group of diesel experts, the authors of this report, met on April 29 and 30, 1987, to resolve issues on diesel generator aging mitigation and improved operations, testing and maintenance. This report documents the conclusions and recommendations of the study group. If these recommendations are put into practice, the experts agreed that many of the engine aging stressors could be either eliminated or their effects could be managed to reduce failures.

The focus of the study group was to 1) address the diesel generator aging stressors resulting from the present nuclear industry testing practices, and 2) propose potential mitigating measures. A new recommended testing program was developed and is documented in this report. It appears that, if implemented, the recommended program could greatly reduce the fast-start aging stressor and improve the operability and reliability of diesel generators.

CONTENTS

FIGURES

1.0 EXECUTIVE SUMMARY AND GENERAL BACKGROUND

Pacific Northwest Laboratory (PNL) was selected to participate in the Nuclear Plant Aging Research (NPAR) Program by the Nuclear Regulatory Commission's (NRC) Office of Nuclear Regulatory Research, Division of Engineering. The results of the completed Phase I diesel generator aging research are documented in a two-volume report (Hoopingarner et al. 1987). In the Phase I research, plant operating experience, data, expert opinion and statistical methods were used to produce a new data base related to aging, reliability improvement, and operational readiness of nuclear service diesel generators.

1.1 EXECUTIVE SUMMARY

A study group of diesel experts met to resolve issues on aging mitigation and operational readiness and this report documents the meeting results. The effects of aging on diesel generator operational readiness are an important safety consideration for nuclear power stations. The diesel generator experts and the PNL staff that comprised the study group have many years of indepth experience and two years of experience on the NPAR diesel aging research task. This experience enabled them to review the testing, aging and regulatory areas and to make recommendations regarding changes in these aspects of the program. The study group concluded that much new information, collected or developed during the NPAR aging research task, provides a basis to recommend and defend a new approach and concept for diesel generator testing that potentially improves reliability. The information and data presented in this document appear to have direct applications to diesel generator regulatory guide revisions, the station blackout issue (US1-A-44) and the reliability issue (GI-B-56).

With the new leak-before-break regulatory determination for large bore reactor piping and other studies, it is increasingly difficult to justify the typical 10-12 second diesel engine fast starting requirements. This issue is discussed further in Section 2.0. The experts concluded that much aging related wear and severe engine service conditions could be avoided if the engine LOCA emergency starting mission requirements were adjusted to a 30 to 60 second range. The conservative position for overall safety appears to favor the longest time period that can be supported by plant type (BWR, PWR) calculations. This relatively small increase in the start time results in many significant advantages, the most important being improved mission reliability and mitigation of aging effects. Further advantages accrue if routine test starting and engine loading sequences and non-LOCA emergency starting time requirements are extended even more than one minute. The experts recommended that plant technical specifications, regulatory guides, IEEE codes and other related regulatory documentation should be modified to permit more appropriate starting and engine loading requirements.

This Technical Evaluation Report is organized into separate topics which follow the agenda of the study group workshop. However, for the regulatory perspective of improved requirements, this separation is not recommended. One integrated program is recommended for diesel generator management. This program would integrate testing, inspection, monitoring, trending, modifications, training and maintenance of the emergency power units. The recommended integrated program is similar to the overall program already in place at many of the small nonnuclear diesel powered electrical utilities operated by some municipalities. Subject to regulatory constraints, many nuclear stations also have some recommended elements in place.

The proposed overall diesel generator program would be relatively easy to establish and it is practical for long term results. It is based upon nuclear and nonnuclear industry experience and results in the elimination of certain aging stressors. The proposed program places this area of safety responsibility directly on the licensees, similar to all other safety issues within nuclear power plants. The regulatory role taken by the NRC should be typical of the role it takes for other plant standby safety equipment.

The proposed program has evolved from research directed to the determination of diesel generator aging under the NPAR program. However, aging mitigation improvements also result in reliability improvements and have other positive NRC and industry influences. For this report no attempt was made to restrict ideas to aging, NRC responsibilities, or other issues. Key elements of the recommended program are shown below:

- It is proposed that the focus of the regulatory assurance of the diesel generator safety function be changed from a statistical basis of successful monthly fast starts to a more predictive monthly testing program. The recommended monthly program is intended to test, monitor, trend and thus predict system operability and absence of aging deterioration. A slower starting schedule is defined for the engine monthly tests which are intended to obtain operating data on about 50 parameters that indicate engine operability status. The test schedule recommended is defined in Section 2.0, and the parameters are defined in Appendix A of this report.

- It is intended that the licensees develop practices for testing, inspection, monitoring and trending into an integrated program for better diesel engine performance and less risk from aging and wear. The general outline is detailed in this report.

- It has been shown in the NPAR diesel aging research and studies that improved training and better maintenance also reduce the risk of deteriorating safety performance by aging and wear and other factors.

- It is proposed that a submittal of the total diesel generator program be prepared for NRC review. Regulatory overview would be based on performance and would parallel the approach for other plant standby safety equipment. The NRC would monitor how well the utilities operate according to their submitted program commitments. The requirements of Regulatory Guide 1.108 would need to be modified to reflect the new recommended regulatory monitoring and monthly testing requirements.

1.2 BACKGROUND

The Phase I research defined which diesel generator components fail and the principal causes of failure. This research also indicated that present plant practices and regulatory requirements for diesel generator testing and periodic engine disassembly are not achieving the desired aging mitigation and reliability goals. The fast-start testing requirements, outlined in Regulatory Guideline 1.108 and plant technical specifications, with its statistical basis, have no predictive capability nor do they measure deterioration, or aging, of the system. In fact, a fast-start test itself may consume the remaining capability of a system component. For example, a starting system component may energize initially and function, but burn out or plug or fail just as the engine fires up and starts to run. For this example, this system component only had to work for 1-3 seconds and the engine operators would have no indication of subsequent failure. Consequently, a subsequent valid emergency demand would not result in a start and run because of the undetected failure. Therefore, a condition-monitoring method that improves on the current diesel generator testing practice is needed.

One approach used in the ongoing Phase II research to resolve the general issues of aging mitigation and engine failures was to convene a study group. The group consisted of the authors of this report, who had worked on the Phase I research and other previous NRC diesel programs. Appendix B lists the qualifications and affiliations of the expert consultants under contract to PNL. The goals of the study group were to develop a broad scope of practical recommendations with good potential for mitigating aging effects. In addition, guidelines to improve diesel-generator operations and maintenance with emphasis on aging concerns were to be considered, including recommended changes to Regulatory Guide 1.108.

This report documents the conclusions and recommendations developed by the study group in a meeting held on April 29 and 30, 1987 at Buena Vista, Colorado. Previously documented information, data and discussion material necessary to introduce and understand the issues and the recommendations are also included in the report.

2.0 TESTING AND INSPECTION

The original basis of the diesel generator testing requirements is discussed in Regulatory Guide 1.108, A. Introduction and B. Discussion. The fast start requirement and reliability goal of 0.99 (at a nominal 50% confidence level) are further defined in the NRC Standard Review Plan, and regulated through the plant technical specifications documentation. The Code of Federal Regulation, 10 CFR Part 50 and appendices, further defines the basis and requirements for diesel generator testing. Should the number of failures to either start or run exceed 1 in 100 tests, the test interval progresses in 4 steps from 31 days to 3 days for 4 or more failures, as defined in Regulatory Guide 1.108, Section C.2.d.

When issued in 1977, Regulatory Guide 1.108 appeared to represent a reasonable and conservative basis for regulation, since the nuclear industry had limited experience with these machines. However, in recent years, accumulating evidence indicates that the large number of tests, and the fast starts in particular, are accelerating the engine-aging process. In 1984, the NRC encouraged nuclear plant owners to request testing changes by issuing Generic Letter 84-15. The intent of this letter was to reduce the number of cold fast starts and to provide relief from excessive testing on earlier licensed plants.

Information from research studies, operating experience, workshops, diesel experts and diesel engine disassembly and examination have shown that the fast-start testing is a major aging stressor, and does little to ensure future engine operability.[a] The engine start time is not given in Regulatory Guide 1.108, which references the technical specifications for each nuclear plant to be used for specifying the diesel start time. These typically are in the order of 10-12 seconds depending upon the assumptions used for the specific plant LOCA analysis coupled with loss of offsite power. Fuel cladding temperature calculations which are defined in 10 CFR 50, Appendix K, are part of the plant analysis used for determining the diesel generator start and loading time. These very conservative cladding temperature calculations also were used to develop the 10-12 second start time range. The fast start is a very severe engine stressor when followed with the typical loading sequence time frame of 30 to 45 seconds to achieve full load.

The possibility for safely increasing the prescribed start time of the diesels is increasing. Some of the reasons for the various regulatory changes being proposed or considered at this time are:

- A major change has already been made to 10 CFR 50, General Design Criterion 4, which accepts leak-before-break analysis and detection methods for the primary large bore piping. Extension to equipment qualification and diesel start time requirements is being considered, but no new criteria have been formulated or released.

(a) The reference list, page R.1 of the report documents the information cited.

- Studies documented by EPRI and others show that the safety function emergency power requirements for the diesel generator system are on the order of 1 to 2 minutes for a LOCA event with a loss of offsite power and 5 minutes, or more, for a loss of offsite power event without a LOCA. (EPRI 1986 a,b)

- The calculational methods of 10 CFR 50, Appendix K, have been shown to be overly conservative, based upon the latest information and computer program models. EPRI and other organizations are performing these new calculations (EPRI 1986 b).

In view of the above discussion and referenced material, it seems reasonable to propose that the emergency power mission requirements be reviewed. A more conservative approach for reduction of aging effects and increased reliability is to define the recommended mission as follows:

1. The onsite emergency power is needed in the time frame of about 60 seconds, assuming both loss of offsite power and a large bore LOCA event, with a recommended engine start time of about 30 seconds. The exact time permitted would depend upon plant specific analysis, but the conservative position is to permit as much time as can be justified to avoid abnormal aging.

2. The onsite emergency power is needed in the time frame of 2 to 10 minutes, assuming a simple loss of offsite power. Again specific plant analysis would be the basis for this mission loading time. The conservative position in this case is closer to 2 to 3 minutes.

3. For testing purposes, the test mission, or schedule, recommended is to test monthly with a 10 minute ramp up to full power (see section 2.2.1) and semi-annually with the shorter time period typical of the large-LOCA event requirements.

2.1 TESTING AND INSPECTION ASSUMPTIONS

The diesel experts involved in the study group were given the following assumptions:

1. For routine testing, the diesel start time should be open to change. The study group may include a new recommended time for consideration

2. The testing frequency and other parameters of Regulatory Guide 1.108 should also be considered to be equally open for discussion and resolution.

3. Comparable utility practices and manufacturer's recommendations should be treated as potential areas of improvement for aging mitigation.

4. Changes to engine designs or extensive modifications to the engines, systems, or plant structures were not considered to be the best approach to the diesel aging concerns, and were found to be not significant in PNL's Phase 1 research (Hoopingarner et. al. 1987). Therefore, design and major modification changes were not considered as a part of the recommendations by the study group, and in any case would be outside of the scope of the NPAR Program.

2.2 TESTING RECOMMENDATIONS

The testing recommendations were extensively discussed as to value, predictability, influence on safety function, aging limitations and other concerns. The resulting testing recommendations from these experts are documented in this section. The group decided that the testing requirements of Regulatory Guide 1.108 should be improved, based upon the abnormal aging and wear presently experienced. This is further documented in Section 3.0 and 5.0 of this report. The group now recommends that new regulatory guidelines should be developed that reduce the fast start stressors and wear. These general requirements are identified in Sections 5.0 and 6.0 of this report.

2.2.1 Periodic Testing Recommended

The diesel experts agreed that there should be no harmful effects of monthly surveillance testing of the diesel engines, provided that the recommendations outlined in this document are followed. Fast start testing has been identified as an aging stressor, especially after long shutdown periods, and should be reduced (Hoopingarner et al. 1987). The approach of the monthly testing should be changed from the statistical basis implied in Regulatory Guide 1.108 to a new goal of determining surveillance information on the operating engines. This information is discussed further in paragraph 2.2.4 and in Appendix A. For operator training and familiarity, monthly runs of approximately 12-14 hours are recommended, so that 3 work shifts may be involved. A start-run-stop routine on each shift is helpful also.

The new purpose of monthly surveillance testing should be to obtain data on key engine performance parameters that indicate that the trends in the engine performance are normal, or that some certain indicator(s) may be revealing a future engine problem. The complete recommended listing of these data points is shown in Appendix A. Section 3.0 further discusses the data to be obtained and which parameters are to be monitored and trended. Where pressures and temperatures are listed for this surveillance test, and appropriate instrumentation is not installed, local or point-of-measurement instrumentation is intended. The point is that the operators should be at the engine observing the operation and becoming familiar with the sights, sounds, and feeling of the engine at operating speed and loads. Taking the required measurements at 1 hour intervals will assist this process of developing familiarity.

Periodic refueling outage testing should include a 24 hour test run which would include a 110% of contract load test for a 2 hour period. This type of test, outlined in Regulatory Guide 1.108 [2.a.(3)], checks the cooling system performance, the fuel system, engine aspiration, turbo charger and several other components. When properly run, this test should have little or no adverse affect on the engine or generator. If LOCA design considerations are retained, a fast start and load test may be performed on an annual, or semi-annual basis. Such a test should be followed by at least a 2 hour run at 75% or greater engine load, to permit engine thermal stresses to be relieved. Fast-start load testing more than twice a year should be avoided to mitigate that aging stressor. Slower starts and loading adequately check the engine and generator systems.

2.2.2 Engine Test Starting and Loading

The present engine fast start preoperational and monthly test program should be modified to reduce the engine aging stressor from that source. It was determined by the experts that a slower starting sequence, outlined below, was equally good at detecting engine problems in almost every instance considered and for each of the failure types discussed. The diesel experts believed that the ultimate regulatory goal of increased diesel reliability would be significantly improved, if the aging effects of the present fast start testing were replaced by an improved test-monitoring-maintenance program. Such a program is defined and recommended in Section 3.1.

For the monthly testing, any maintenance testing and the majority of the preoperational testing the start-sequence should be a gradual increase in load over an approximate 10 minute time period. This is typical of the way in which diesel engines are started in normal small utility operations. In these non-nuclear applications, it is not unusual to experience over 100,000 hours of operation in a 35 to 50 year period of use, with 20,000 or more hours between major overhauls. If an engine has not been fast started by a reactor operational response signal in a six month time period, it may be fast-start tested, chiefly to check that the loading sequence circuits operate within acceptable limits and time. An alternate procedure of electronic sequence checking may also be acceptable. If the LOCA event is removed as a design consideration, then all fast start testing should be eliminated. Engine starting should be according to the following recommended considerations.

1. For testing purposes, the engine should be started and idled for a few minutes while checking for correct parameters and unusual engine noise levels. The engine should not be idled at or near a serious torsional critical speed. (See item 4). Up to 1/2 hour in this idle mode appears safe for all engine types. However, 5 to 10 minutes is recommended and is adequate for checking most engines and the key parameters of interest. Owners of 2-cycle port scavenged engines need to limit idle time to avoid exhaust manifold fires, and the 10 minute period is a more appropriate maximum for these engines.

2. The engine should be brought up to speed and loaded over a time period of about 10 minutes to achieve full load. By idling for a few minutes, and gradually loading the engine in this way, the piston and cylinder liner may thermally expand together and greatly reduce the

wear rates on the components. Other abnormal aging stressors are also reduced by this slow-loading sequence.

3. For regulatory purposes, full load on the engine should be defined as the plant design load and any modifications to that load. This design load is about 75% to 90% of the engine rated capacity. This design load is documented as the engine "Contract Load," which is written into the purchase specification and the engine technical specifications. Testing at 110% of full load should then be based on this contract or plant load. The engines should not be started for test purposes and run immediately up to 110% of the contract load. Stability should be achieved first at the contract load, see paragraph 2.2.3.

4. A torsional analysis should be made and verified by test for each engine type and model similar to that made by the Transamerica De Laval Incorporated (TDI) Owners Group for those engines (PNL 1985). Plant procedures should then indicate where these engine torsional vibration critical speeds are located. For routine starts, the accelerating engine should pass through these critical speeds quickly, but not at full fuel rack setting, i.e. not at maximum acceleration.

2.2.3 Engine Test Operation

It is the opinion of the diesel experts that there are certain benefits in increasing the engine operating time period. The concept of stability is one of the significant considerations. Most importantly, it allows the engine to achieve stable conditions throughout all components and systems. This alleviates many stressful conditions and permits detection of developing abnormalities. Operator training and operating procedures should emphasize that certain engine key parameters, chiefly pressures and temperatures, should be monitored for stability, before changing engine loads under test conditions. For example, after loading, cooling water temperature should increase to an acceptable level and then level off within a short time, indicating stability for that parameter. This stability time period varies by parameter and engine type, but is usually within several minutes. An engine should not be test loaded to full load or overload until stability at lower loads is verified.

After an engine fast start with full loading, overload testing, or other unusual condition whereby the engine is subjected to high thermal transients, the engines should be operated for a period of at least 2 hours at or near design-load conditions. The benefit of such operation is to allow engine thermal stresses to equalize and relax. This avoids distortion, metal creep, and other problems.

Additional general benefits of longer routine test operations are to dry out moisture in the lubricating oil, to circulate and consume fuel oil, to help avoid certain fuel oil aging problems and to acquaint the operators with normal engine operation and sound levels. Sometimes operators or management have the misperception that diesel engines are delicate machines. Routine operation for longer time periods should help develop the correct concept that diesel engines are designed for reliable long-term operation.

2.2.4 Testing After Specific Faults and Maintenance

The present general practice is to fast start the engine after a malfunction and/or any significant maintenance, to ensure engine operability. Because of aging concerns, the experts did not agree with this practice and believed that other tests or requalification measures were often superior for this purpose. For example, malfunctions attributed to human error or a clearly defined fault should only require the specific correction for the error or fault and an appropriate local component test. Maintenance on a specific engine system or component should only require a subsystem or component test to ensure operability. In both of these examples, the engine should not always be started for testing. This implies that the diesel generator owner has carefully trained operators and maintenance personnel, and has procedures and a quality assurance program that are effective. The clearing and removal of electrical and mechanical safety isolation points and valve closures performed for maintenance must be meticulous, and where possible, local tests should be performed to ensure operability of the system or component before returning the diesel generator system to operational status.

In cases of major engine rebuilding, where highly stressed rotating or moving components are replaced (crankshaft and crank rods, for example), the engine should be operated up to a minimum of 3×10^6 cycles at design loads before the engine is returned to full operational status. A load cycle is assumed to be RPM/2, for a 4-cycle engine. Engine cylinder liners, bearings and generally pistons are not considered to be highly stressed, for example, and would be exempt from such fatigue proof-testing.

2.3 INSPECTION RECOMMENDATIONS

Diesel engines used for marine and conventional stationary power applications receive weekly, monthly and yearly inspections, each with different goals and completeness. Diesels used for nuclear emergency power applications were perceived to be used only a small fraction of the time and so typically less inspections were scheduled and performed. The aging research program for diesels has developed information and data to support the concept that the nuclear station application, with the present testing requirements, is in reality severe service for the engine and several of the engine support systems. Thus, a more complete inspection program appears to be appropriate and should help mitigate certain aging failure processes and increase the engine start and run reliability. Note that additional monthly and yearly monitoring requirements are discussed in Section 3.0 of this report.

The weekly and monthly inspections should be made at the same time and by the same personnel who have the preventative maintenance responsibilities for the diesel generators. The yearly, or outage, inspection team should have, in addition to the preventative maintenance personnel, a plant engineer, manufacturers' representatives or an outside consultant to assist in the inspection.

All inspections should be documented, should follow a written checklist and should be signed off according to the plant quality assurance program for each level of inspection.

2.3.1 Weekly Inspections

In general, the inspections should follow the good practice standards for conventional diesel generator systems and the manufacturer's recommendations. The inspection personnel should check for oil and water leaks, other signs of vibration-induced loosening and the environmental stressor conditions identified in the aging research (Hoopingarner et al. 1987). Such stressors collectively represent the causes of over 40 percent of the diesel failures. In addition, the inspection/preventative maintenance personnel should oil the engine governor and fuel linkage and check for free operation and movement. To complete the weekly inspections the following points should be included in the plant inspection program:

- engine keep warm system for oil/water heating for correct operation and the temperature specified
- lubrication oil levels; engine, governor, turbocharger and outboard bearing
- engine prelube system for correct oil level or pressure
- engine cooling system, valve alignments and in some cases radiator levels
- other valve alignments, especially after any maintenance has been performed, which would require isolations to be performed
- breaker alignments and relays, especially after maintenance periods
- air start system pressure, system moisture downstream of the dryers and valve alignment.

2.3.2 Monthly and Quarterly Inspections

These inspections probably have the most value if they are scheduled to closely follow the scheduled test start-run operating period. Signs of vibration-induced loosening and problems associated with environmental stressors may be detected before they have time to progress to a more serious condition or failure mode.

Preventative maintenance and inspections should focus on those systems, subsystems and components identified in the diesel generator aging research (Hoopingarner et al. 1987). For example, the instrument and control system and the governor should receive special attention, since they are the system and component with the most failures. The diesel generator support systems should receive more attention than the diesel power train or the generator unit since the aging report (Hoopingarner et al. 1987) shows a much higher failure rate in the support systems compared to either the engine or the generator.

Some monthly inspection items should be done while the engine is running. Inspections should include, but are not limited to, the following significant items:

- Check the air filters and the louver systems in the combustion air and cooling air systems.
- Check the fuel oil dual filter manual valve position. The valve should not be in the middle position, but should be directing the flow to one specific filter element. The other element should be held in reserve for failure recovery and emergency use.
- Check for vibration loosened components or vibration induced damage.
- If a lube oil filter is changed, sample the surface deposits and cut open the filter and inspect it for unusual contamination and wear particles.
- Check diesel exhaust system for signs of leaking (engine running).
- Check diesel exhaust smoke color, at midpoint of the monthly test run, or smoke meter reading (engine running).
- The monthly inspection should include the weekly inspection items and should replace one weekly inspection.

The quarterly inspections and preventative maintenance should include the following:

- Clean and inspect the strainers and filters in the starting air system.
- Sample fuel oil in storage for jelly and gum formation and bacteria growth at any condensate fuel-oil interface.
- Sample lubrication oil for wear particles, water contamination and oxidation. Pentane insolubles should not exceed 4 and the Ph should not be below 4 nor above 7. The amount of silicon in the oil, above the original level (Silicon Fluoride anti-foam agent), is dirt contamination and is abrasive.
- Inspect the fuel oil filters and replace at the recommended frequency or as shown by the station experience.
- Inspect the combustion air and exhaust manifolds for oil and carbon deposits (fire hazard). Two-cycle engines especially benefit from this inspection.

- Inspect relay enclosures and control cabinets for dust and dirt and remove it where necessary.

- All diesel generator skid-mounted equipment should receive at least a visual check for vibration damage and loosening. Valve operators, instruments, equipment mounts, fittings and other important equipment should be checked, especially those items which have failed in the past from this engine stressor. Checks with the engine running are also beneficial for vibration damage or loosening.

2.3.3 Yearly or Refueling Outage Inspections

The refueling outage inspection goals should include a significant review of previous local engine failure points, and should cover the manufacturer's recommendations for inspection and any special tests and inspections needed to resolve any diesel generator monitoring adverse trends or other indication of problems. The study group recommended that an expert diesel consultant, a manufacturer's representative, or a well-qualified utility staff engineer provide technical direction and assistance for the yearly inspection effort.

A diesel generator unit that is being effectively monitored and inspected should not be disassembled simply to inspect it for potential aging and wear. Since the probability of inducing a potential failure is at least as high as the potential of discovering any latent defects, the diesel experts could not recommend significant engine disassembly for inspection purposes. Instead, they recommended an effective monitoring and trending program, such as described in Section 3.0 of this report, which should be more effective in identifying deteriorating engine conditions than engine disassembly and inspection.

The yearly inspection should include the following items to achieve the intended safety goals:

- Inspect previous repairs made to correct specific engine failures to ensure that there are no visual or other obvious signs of recurrence. Judgments will have to be made as to the scope, accessibility, and importance of the items in this inspection listing.

- Inspect items recommended by the manufacturer

- Inspect engine liner wear by visual inspection from the crankcase access ports

- Inspect bearing wear and appearance by selecting two rod bearings for inspection during each outage

- Perform crankshaft deflection test and alignment for both hot and cold engine conditions.

3.0 MONITORING AND TRENDING

Monitoring and trending are treated separately from testing and inspection in this report; however, all four items are related. Any future use of the material in this report should also preserve the concept that testing, monitoring, inspection and trending are simply various aspects of an overall process.

To appreciate more fully the benefits of monitoring and trending, one should be aware of the influence of maintenance on failure rates. Various systems, components, machines and other hardware items respond to major maintenance or replacement in various ways. Airline maintenance research has shown that most hardware items fit into one of four response patterns (Engineering News, 1983). Figures 3.1 through 3.4 show the influence of maintenance on the failure rate response patterns. Each figure caption states the percentage of components associated with the specific response pattern shown from the referenced research. During the maintenance period shown in the figures, equipment is given a maintenance teardown inspection, components may be replaced and the unit is reassembled.

Diesel generator systems consist of thousands of components with many different functions. The percentages of components that may fit into each response pattern have not been determined for the diesel generator system, but should be not too far from the experience of the referenced research. The U.S. Navy has shipboard experience which supports the response shown in Figure 3.4 (32% of the components have increased failure rates for periods up to five years).

When these maintenance response percentages are coupled with the current nuclear industry diesel generator testing practices the probability of aging mitigation and reliability improvement is not encouraging. In simplistic terms, diesel generators are periodically tested until a component fails. Failed components are maintained or replaced 78% of the time according to the Phase I results. There may be less than a 20% chance of improving the failure rate even for a short time, assuming the percentages of Figures 3.1 and 3.2 apply. When this scenario is evaluated, the current regulatory approach appears weak.

In view of the generally good reliability results of most diesel generator systems (Nuclear Engineering International 1987), it is obvious that the licensees are doing inspections, monitoring and trending and using good quality assurance practices. Such practices keep the industry wide results generally positive. It appeared reasonable to the diesel experts to recommend that the regulatory overview be changed to reviewing and monitoring each utility for their overall diesel program and thus encouraging the utilities to review and modify their inspection, monitoring and trending activities associated with the diesel generators. Section 5.0 details this recommendation. (Scheible and McElroy 1987) provides additional information on trending.

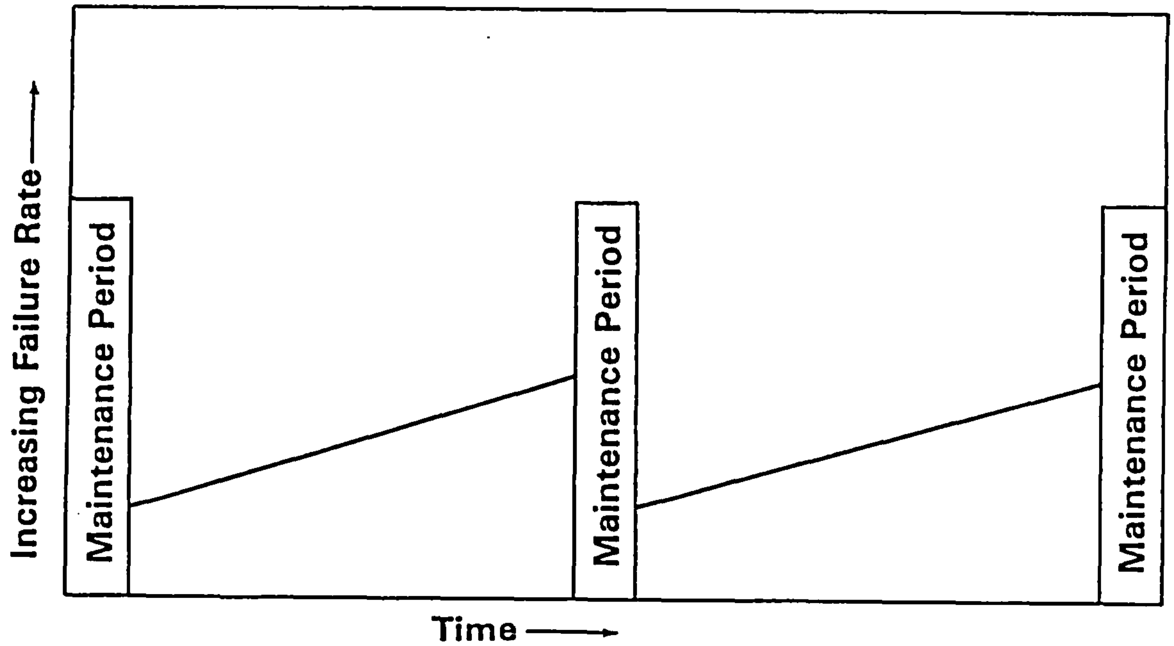

FIGURE 3.1. Mechanical Failure Pattern 1, Representing only 8% of the Components Studied. Failure Rate Reduction Due to Maintenance.

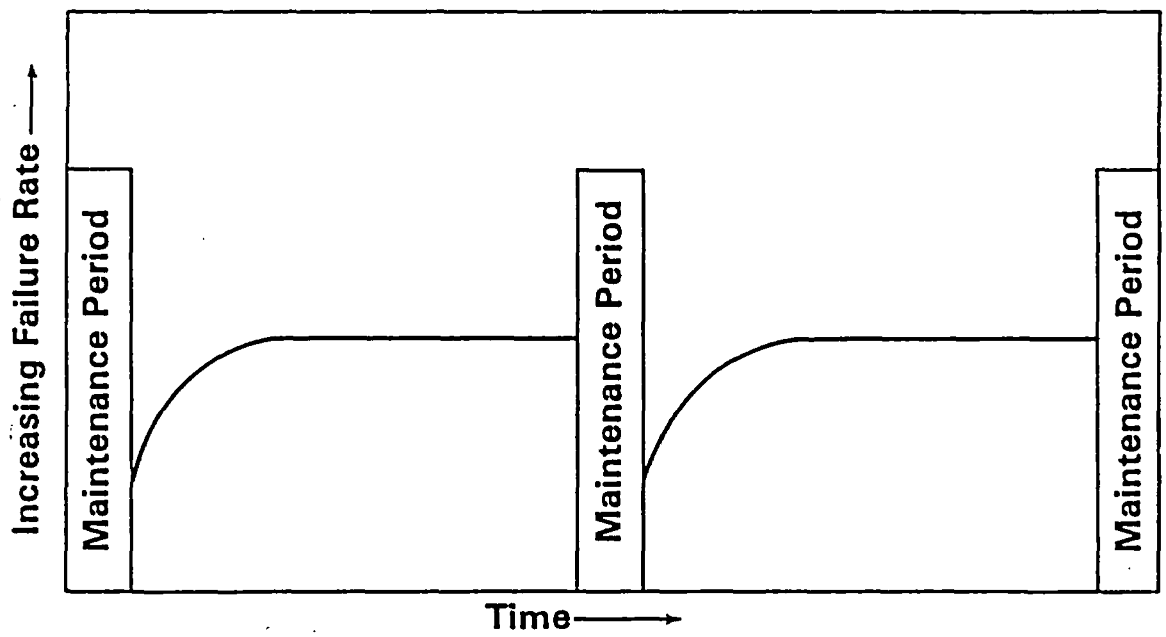

FIGURE 3.2. Mechanical Failure Pattern 2, Representing 11% of the Components Studied. Early Maintenance Benefit Only.

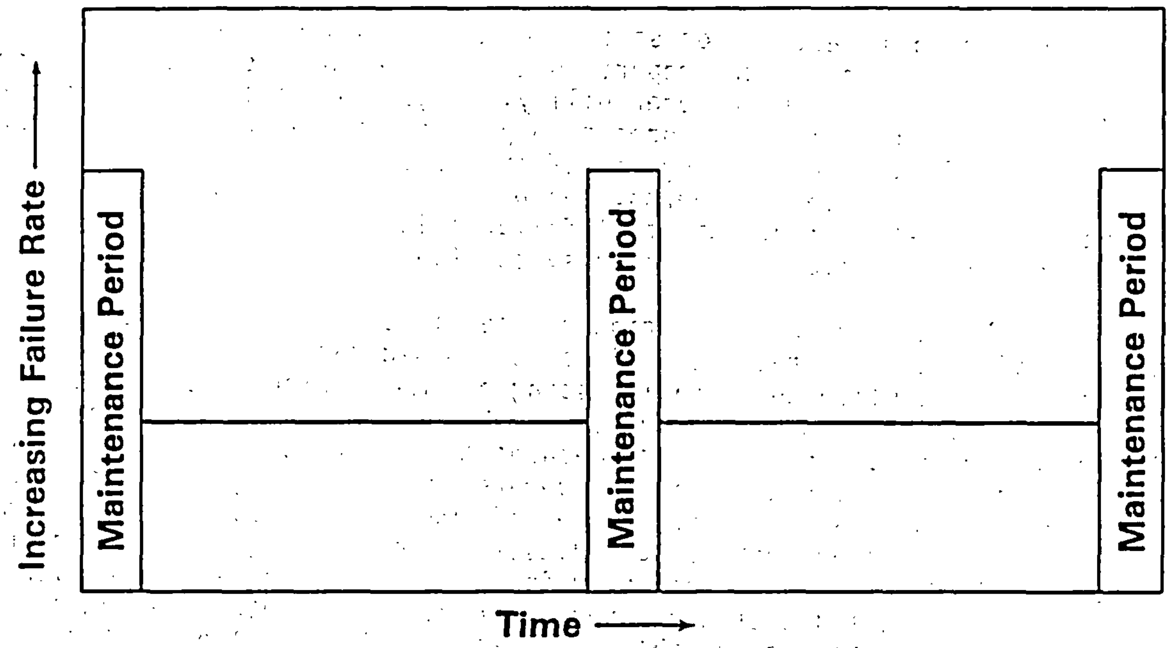

FIGURE 3.3. Mechanical Failure Pattern 3, Representing 15% of the Components Studied. Maintenance Does Not Affect Failure Rate.

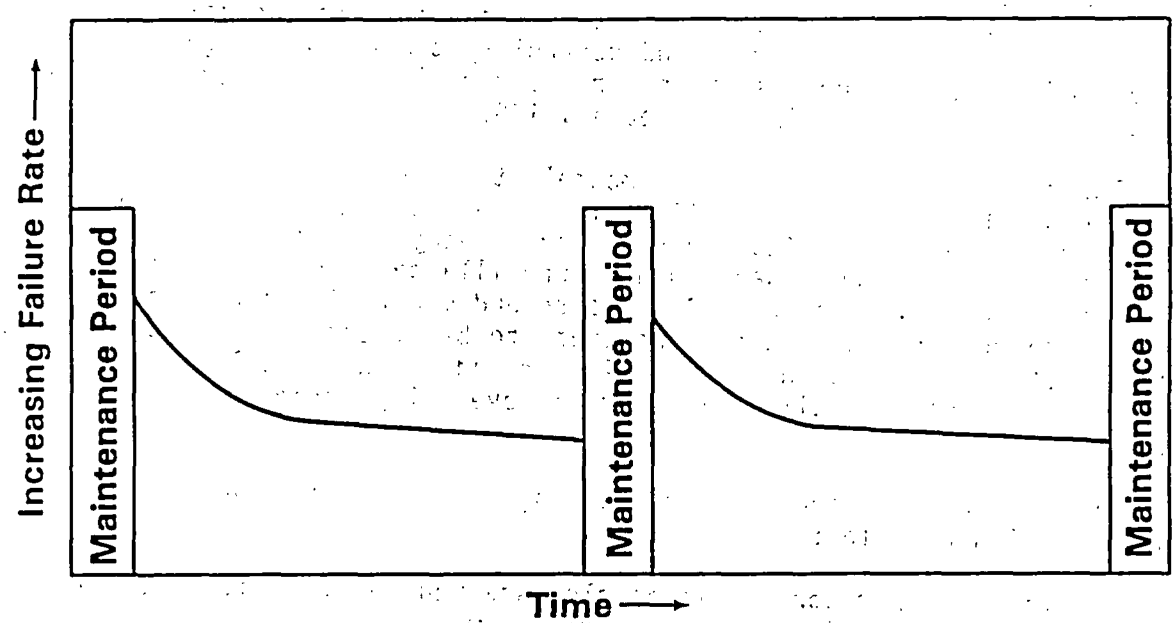

FIGURE 3.4. Mechanical Failure Pattern 4, Representing 66% of the Components Studied. Maintenance Increases the Failure Rate.

3.1 MONTHLY MONITORING

Monthly start-run testing for statistical information (Regulatory Guide 1.108 requirements) with failure reporting and maintenance is a reactive process with no assurance of future operability. A good overall program of testing, monitoring and trending is a proactive process with a very good assurance of future operability. Such a program, often called "condition monitoring," was recommended by the diesel experts. An overall diesel generator program should be able to detect many potential failures in incipient states prior to the actual component failure or loss-of-system function.

For monthly testing and monitoring of the diesel generator system, the study group offered three recommendations for consideration. The first recommendation is to establish an overall testing and monitoring system that identifies for each specific engine and system the key parameters and indicators which are precursors to known failure mechanisms or that show degraded performance. The second recommendation is to operate the diesel engine and obtain specific engine and generator performance information and data. This recommendation had the highest priority of the diesel experts. It generally requires little or no added instrumentation or equipment. The third recommendation is to test and monitor the diesel generator instrument and control system to ensure that the circuits are operable and that key electrical parameters are not deteriorating. This circuit diagnostic equipment has not been developed to a point where it is common practice at the present time, but it is commercially available and has been used on other types of electrical systems for this purpose. When using such diagnostic equipment, the diesel-generator system need not be operating to obtain data and monitor the status of the instrument and control system. Thus, it adds no known stressors to the aging/ wear concerns for the system. The instrument and control system has the highest incidence of failure of all the support systems for the diesel generator system, according to research results (Hoopingarner et al. 1987).

The study group recommended a monthly testing and monitoring approach for diesel generators that is significantly different from the approach outlined in Regulatory Guide 1.108. Testing has been already introduced in Section 2.2 of this report. The recommended monthly surveillance test and monitoring schedule is shown in detail in Appendix A. The second monitoring part recommended is a simple data collection process. However, to be effective, the month-to-month test variables should be held to a minimum and the data collection and recording process should be well defined by the overall program and supporting procedures.

The second recommendation for testing and monitoring should follow the guidelines listed below:

1. The diesel generator should be slow started and loaded, as already discussed, to avoid the fast-start aging stressor.

2. The diesel unit should then be loaded and run at defined and consistent loads from month-to-month. The test load should be in the

range of 70 to 90 percent of the engine nameplate rated load which should correspond to the plant full emergency load.

3. The recommended diesel run time is approximately 12-14 hours, and should be spread over three shifts. This allows more plant personnel to be involved and gain familiarity and training with the equipment.

4. The diesel unit should be started about 2 hours before the end of a work shift. After engine stability is achieved the first set(s) of data for monitoring the engine operation should be collected by the first shift personnel. Another set of monitoring data should be collected 4-5 hours later at a minimum. In actuality, the experts suggested that data be collected each hour, with the further recommendation that the minimum number of data collections should be three (one from each shift). The last data set(s) should be collected by the third work shift.

5. Since the data is only collected each month, and some work shifts are not involved each month, it is important that the data collection sheets show certain information. The procedures should list any minimum or maximum values for each significant parameter. The operators should also be able to refer to past data such as the last and average values taken for each significant parameter being monitored. Following this recommendation would reduce operator errors, add to the safety of the testing process, and highlight any changes in equipment performance.

6. The diesel generator test program may include a system startup on each shift without damage to the engines. This would help in training and general familiarity for the station personnel.

7. The routine monitoring and trending of diesel engine base vibration per se and the diesel start time are not recommended. These parameters have normal variations that are too large and other data points are available which are easier to interpret and give equivalent information. The vibration monitoring of the generator gives much better results and may be used for monitoring.

8. The data collection, recording, and instrument calibration processes and procedures should follow the station quality assurance requirements for similar data collection and for similar safety functions.

The third recommendation for monitoring consists of a computer run module that upon command would check key electronic and electrical circuits to ensure that they appear to be in an operational state. Continuity, resistance, function, switching and other important measurements can be performed very quickly. A manual circuit testing process is not recommended; it generally is too costly (labor) for the results achieved and may require job skills not available on a shift schedule.

Automatic or computer run modules for circuit diagnostic testing have been designed and developed for military and other applications, but have not been reduced to practice for the diesel generator application. Therefore, the recommendation is to encourage the development of such specific equipment for the diesel generator system.

3.2 OTHER PERIODIC MONITORING

Certain aging related parameters and data should be collected on a quarterly basis and during outage time periods. Fuel oil, lubricating oil, and cooling water analyses should be made quarterly and carefully monitored so that aging mitigating measures and actions may be taken. Shaft deflection tests should be made during the refueling outage. The engine should also be carefully monitored for the data listed in Appendix A once each hour during the 110% load run. The data of interest is chiefly the cooling and lubrication system performance and cylinder and turbocharger temperatures during this test.

3.3 TRENDING

Without parameter trending, the monitoring recommendations have little predictive value to the licensees and the NRC. A good trending program is labor intensive to set up and get running. After that point, for regulatory Value/Impact considerations, the cost savings in avoided equipment damage and down time are estimated to have a payback period of less than one year. Thus, no NRC backfit rule problems are predicted. (Scheible and McElroy 1987) outline additional examples of cost savings experienced.

From the regulatory viewpoint, the generally favorable economic experience reported makes it easier to get good performance from the licensees. Since it is in their best economic interest to do a good job of monitoring and trending, the regulatory controls have to be less prescriptive.

The concept of trending appears simple, but there is an experience requirement. To predict failure, or the time at which performance is less than the prescribed performance limit, one has to know both when and how the data being trended approaches the limit. The limit may be either a maximum or a minimum (but rarely both) for a single parameter.

For example, a diesel engine bearing is designed for very long life and bearing temperature is an easy to measure parameter, which changes very slowly and appears to be a straight horizontal line. However, at failure the temperature rise is very rapid and may progress from normal to bearing failure in a matter of minutes. Thus, the way that bearings fail has to be known (experience) before an end-of-life or a performance limit can be predicted. Other bearing condition indicators exist that give much better results. Fortunately, the experience with diesel engines spans many decades and the trending should not be too difficult, if experienced personnel are enlisted to help establish trend limits and the expected failure patterns.

The variable engine parameters listed in Appendix A should be monitored and trended. Load and governor settings, for example, are not variables that need to be trended, but they do need to be uniform from month-to-month.

4.0 MODIFICATIONS, TRAINING AND MAINTENANCE

Certain modifications, training and maintenance requirements must be addressed to support aging mitigation and the testing described in this report. The recommendations by the experts for these requirements are characterized as "good practice." Many of these recommendations are already in place and established as standard practice by some utilities, which use diesel engines for base-load service. Nuclear station practice is also developing better maintenance, training and modification improvements in general agreement with the recommendations.

4.1 MODIFICATIONS

Diesel engine prelube and keep-warm heating systems have been added already by the utilities to lessen the wear and aging effects of emergency fast starts. The study group recommended that any engines that have not been so modified should have these modifications added. Another common modification being considered and implemented is to move instruments and controls, where possible, from the engine or engine skid to another off-skid location to isolate the engine vibrations. This avoids the aging influence of vibration which was the chief stressor found in the collective diesel operating experience of the licensees and reported in (Hoopingarner et al. 1987). This modification is highly recommended.

4.1.1 New Modifications Recommended

The modifications required to change the monthly testing program from the present statistical basis to meet Regulatory Guide 1.108 requirements to a monitoring and trending basis as recommended by the study group consist primarily of procedural changes with a few local instruments to be added for some installations. These missing instruments vary among the various engines and vendors. The vast majority are already installed. Some should be upgraded to better accuracy, if inadequate for the intended purpose as now installed.

Another modification that is low cost and highly recommended by the study group is to add manual starting provisions to the engines. This will permit trained operators to start an engine by going to the diesel generator room for recovery from station blackout. The modification, in concept, consists of levers added to the fuel control mechanism and some local control provisions needed to override any instrument and control system components that could prevent the engine from being manually started. Manually operated valves should be available for supplying startup air to the engine. A trained operator would manipulate the start-air and fuel-control levers to start the engine and bring it to operating speed. This modification would allow a start within 5 minutes. Actually, an experienced operator should be able to manually start an engine and begin to incrementally load it in about 1 minute, assuming he is present at the diesel and has normal emergency lights and related D.C. power. The other 4 minutes is assumed to be needed to pass through security check points and reach the diesel from other plant areas. Except in the one case of a LOCA with a loss of offsite power, this should prevent any core damage and also RCP seal damage (G.I.-23 issue). After starting, the engine governor would control engine speed while the plant electrical loads are energized in the proper sequence from the plant control room.

A procedure modification and perhaps electrical timers for the auxiliary lube oil pump (for Fairbanks Morse opposed piston diesels) that would assist in the lubrication of the upper crankshaft assembly before planned or test starts, is also recommended. This lube oil pump should be turned on for about 1 to 2 minutes before the engine is planned to start. As an alternative, it may be possible to increase the existing lube oil standby circulating pump output pressure several minutes before starting. A similar modification for all diesel engine types would reduce aging and wear of the intake and exhaust valve assemblies, which now do not receive standby circulating lubricating oil. Regulatory guidance and perhaps plant technical specifications will have to be slightly changed to permit such planned prelube for planned starts. This should not increase regulatory concerns with unplanned starts without such prelube conditioning. The reason for no regulatory problems is that there are no observable effects on the start time or short-term reliability by prelube practices.

4.1.2 Optional Modifications

Section 3.1 outlined a recommendation to test and monitor the diesel-generator instrument and control system for function and status. This would require the addition of circuit diagnostic equipment. The NRC and industry costs, scope, and other information needed before a final recommendation can be made have not been completed for such equipment. Therefore, this modification is only listed for consideration at this time, with the recommendation that the missing NRC Value/impact level of information be collected as part of the Phase II research in the diesel generator aging task.

4.2 TRAINING

To avoid maintenance induced aging stressors, PNL recommended that engine and governor maintenance training needs improvement. Operator training to overcome failure-to-start and run problems and manual starting of the engines is also perceived as a need. Two persons, at a minimum, for each nuclear unit should be given maintenance training equivalent to that offered by the diesel engine and governor manufacturers. Such persons should be at the working level, and should be used to train and develop the skills in other maintenance personnel. Many utilities already exceed these minimum requirements, but from time-to-time all licensees need to evaluate the training of new personnel or to retrain them after certain time periods have passed.

The Phase I Aging Study, Volume I (Hoopingarner et al. 1987) describes the systems, components and the stressors most likely to be involved in diesel generator aging and failures. Additional training on those items with the higher failure percentages, such as the instrument and control system and the governor, should give the best results.

Training in the use of the trending and monitoring data sheets and procedures will also be required to implement the recommendations in this report.

The use of failure fault diagrams with defined corrective actions for plant operators was also discussed and recommended. These trouble-shooting aids list information on the most common causes of failure to start and run along with the sequence of corrective actions. The availability of such information speeds up the process of starting the engines in a real plant emergency. NRC/NRR may wish to address this issue as part of the review of the overall diesel generator program plan submitted by the Utilities, as recommended in this report.

4.3 MAINTENANCE

The chief recommendation for maintenance is, in conjunction with an adequate monitoring and trending program, to avoid teardown of the engines simply for the purpose of inspection. As Figures 3.1 through 3.4 indicate, this may have an overall adverse influence on the system failure rate. Any significant components not directly or indirectly monitored would continue with the present maintenance program. This is not to imply that engine and system components with a known qualified life would be operated past their qualified time or operating hour limits, simply because monitoring and trending showed no difficulties. However, such information may be used as a basis for requalifying the components to a longer time period, as another issue not within the NPAR scope for further study.

The next recommendation is to ensure that licensee maintenance organizations do not treat the engine governors as "black boxes," which are often left alone until a failure occurs. The governors must have regular and careful maintenance, adjustment, and preventative maintenance based on a firm understanding (training) of the governor and its service needs.

Spare fuel pumps, governors and other major components that could be interchanged to allow maintenance may be attractive to some plant operators and management. This increases flexibility, choice of onsite and offsite maintenance locations, and ensures that patch-up repairs are not performed simply to meet the 72-hour technical specification time limits or other operational constraints. The whole area of spare parts needs careful evaluation. With a good monitoring and trending program some aging related failures can be predicted in time to order spare parts. Other components with random failure patterns, or that are not directly monitored and trended, may benefit from additional spare parts and make it easier to meet the 72-hour rule.

The last maintenance point is that normal engine vibrations have a known and severe influence on the control system, instrument operation and calibration. Vibration was the diesel generator stressor found to cause the highest percentage of failures in the PNL research (Hoopingarner et al. 1987). The obvious recommendation is that engine preventative maintenance should be increased to mitigate the aging and wear results of this stressor and that any monitoring program should have engine or engine skid mounted instrument calibration well under control for this environmental factor. The point is that, even with a well running engine, vibration can not be eliminated, but problems can be predicted which are caused by vibration. One of these problems is that monitoring and trending instrumentation may also give erroneous information because of vibration-induced degradation. The maintenance program needs to address this issue, and increase such instrumentation calibration and preventative maintenance service.

5.0 REGULATORY MONITORING ACTIONS RECOMMENDED

The discussion and recommendations in Sections 5.0 and 6.0 in this report are based on the assumption that all previous recommendations are put into practice by the NRC and the licensees. These two sections are not intended to be exhaustive in their treatment of these purely regulatory concerns, but only to document the scope of the discussion in the workshop. Section 5.0 illustrates the concepts of how the NRC overview of diesel generator monitoring and trending could be accomplished and Section 6.0 addresses the most essential changes of Regulatory Guide 1.108 to permit such a change in the testing concept to proceed.

5.1 REGULATORY CONCEPTS

The NRC minimum acceptability of 95% reliability, or better, is practical and after some experience in the recommended program, may be increased somewhat. To assure operational readiness, it is recommended that performance of the safety function on plant demand should be the basis for acceptability, rather than the current test program. This is essentially the process the NRC uses for all other plant equipment. A demand is either a test signal or an actual plant event requiring a diesel generator to start and run, regardless of the overall duration of the signal or event.

This report proposes that a new regulatory overview be adopted that consists of an entirely new program for assuring diesel generator operational readiness. As discussed in this report, it consists of a new requirement that the licensees should be required to have an approved diesel generator program following acceptable guidelines to be developed later. The proposed program and guidelines outlined in this report is a balanced approach where testing, inspections, monitoring and trending, training, maintenance and modifications all have appropriate importance.

It is proposed that the NRC should not track, process or analyze any diesel generator monitoring and trending data on a routine basis. This would all be done by the utilities. The NRC should be concerned only with excessive numbers of failures to respond to valid demands the same as for other major safety components such as the high pressure safety injection (HPSI) pumps and motors.

Monitoring and trending of diesel generator operational readiness and performance parameters would be the basis of licensee reports to the NRC rather than the statistical basis now reported. The NRC overview should not be prescriptive, but rather evaluate the licensee's maintenance, testing, inspection, monitoring and trending program for diesel generators.

The NRC would evaluate the overall licensee's management and performance on the diesel generator and give independent reports on performance. This would place the diesel generator regulatory process in the same conceptual process as used for all other significant plant standby safety equipment. The advantages of the proposed regulatory approach are:

- The new program is predictive and gives much more assurance of future engine operability, than current requirements.

- Rather than a single data point each month (i.e., a successful or unsuccessful diesel start and run), the recommended approach would give about 150 data points for utility evaluation. Degraded performance would be reported to the NRC for independent evaluation.

- Information on aging, potential common mode failures and other risk sensitive data would be available to the NRC through the utilities trending data and the overall diesel program.

- It minimizes the present severe fast-start aging and wear stressor found in combinations of plant technical specifications, equipment capabilities and Regulatory Guide 1.108 requirements.

- The proposed program is not costly to implement by either the NRC or the industry and should increase NRC's confidence in the safety performance of the diesel generator system.

- Due to statistical limitations, rapid and significant performance degradation may not be detected for many months by following the testing requirements of Regulatory Guide 1.108. The proposed testing and monitoring methods avoid this problem, and significant performance degradation would normally be detected during the next subsequent engine test period.

6.0 REGULATORY GUIDES AND STANDARDS

The workshop participants reviewed the Regulatory Guides applicable to the diesel generators. Only Regulatory Guide 1.108 was significantly involved in changes required to permit the overall recommended program to proceed as documented in this report. This guide is included as Appendix D and edited to show the scope of essential recommended deletions and additions.

Technical specifications, and some other nuclear standards such as IEEE-387 will also be affected. However, such changes were not considered or documented at the workshop sessions.

REFERENCES

a. EPRI. 1986a. The Reliability of Emergency Diesel Generators at U.S. Nuclear Power Plants. EPRI-NSAC-108, Electric Power Research Institute, Palo Alto, California.

b. EPRI. 1986b. Effect of Diesel Start Time on BWR/6 Peak Cladding Temperature-Licensing Basis Sensitivity Calculations, EPRI-NSAC-96, Electric Power Research Institute, Palo Alto, California.

c. PNL. 1985. Review of Resolution of Known Problems in Engine Components for Transamerica DeLaval Inc. Emergency Diesel Generators. PNL-5600. Pacific Northwest Laboratory, Richland, Washington.

d. Hoopingarner, K. R. J. W. Vause, D. A. Dingee and J. F. Nesbitt. August 1987. Aging of Nuclear Station Diesel Generators: Evaluation of Operating and Expert Experience. Phase I Study, Volume 1, NUREG/CR-4590, PNL-5832, prepared by Pacific Northwest Laboratory for the U.S. Nuclear Regulatory Commission, Washington, D.C.

e. Hoopingarner, K. R. and J. W. Vause. August 1987. Aging of Nuclear Station Diesel Generators: Evaluation of Operating and Expert Experience. Workshop, Volume II, NUREG/CR-4590. PNL-5832, prepared by Pacific Northwest Laboratory for the U.S. Nuclear Regulatory Commission, Washington, D.C.

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APPENDIX A

RECOMMENDED DIESEL GENERATOR MONTHLY TEST PARAMETERS

APPENDIX A

RECOMMENDED DIESEL GENERATOR MONTHLY TEST PARAMETERS

This appendix gives a suggested list of monthly test parameters that should be monitored to trend the diesel generators for assurance of future operability. The listed parameters are generic by necessity due to the existence of many engine manufactures and model types. The recommended testing is an extension of that required by standard IEEE-749.

Fuel consumption tests at each refueling outage, load acceleration tests and similar specific tests are not listed in this appendix. Appendix A is intended only for periodic monthly testing to determine the presence or absence of indicators of engine operability. Special tests may warrant the assistance of diesel generator experts, or specialists, generally not available on the plant technical staff.

All monthly test programs should be documented, should follow a written checklist and should be signed off according to the plant quality assurance program.

Parameter	Requirements	
General Data	**Required**	**Optional**
Date of test	X	
Time of test	X	
Total hours on engine (hour meter)	X	
Starting air pressure		X
Engine speed or electrical frequency	X	
Generator Data (Alternator)[a]		
kW	X	
Volts	X	
Kilovars	X	
Alternator winding temperature	X	
Alternator bearing temperature (One or two	X	
bearings) (Oil temperature) amps per phase	X	
Engine Cooling Water		
Water pressure to engine	X	
Water temperature to and from engine	X	
Water pressure to and from engine water cooler	X	
Water temperature to and from engine water cooler (could be radiator)	X	
Water pressure to and from raw water cooler[b]	X	
Water temperature to and from raw water cooler[b]	X	
Water pressure to and from turbocharger		X
Water temperature to and from turbocharger	X	
Water pressure to and from turbocharger after cooler[b]	X	
Water temperature to and from turbocharger after cooler	X	
Water pressure and temperature to and from L.O. cooler	X	
Jacket water pump pressure (to and from)		X
Lubricating Oil		
Oil pressure to engine	X	
Oil temperature to and from engine (oil sump temperature)	X	
Oil pressure to and from L.O. filter	X	
Oil temperature to and from L.O. cooler	X	
Oil pressure to and from L.O. cooler	X	

Parameter General Data	Requirements Required	Optional
Lubricating Oil (contd)		
Oil pressure to turbocharger	X	
Oil temperature to and from turbocharger	X	
Air to Engine		
Ambient air temperature	X	
Barometric pressure	X	
Relative humidity		X
Air pressure to turbocharger[(b)]		X
Air temperature to turbocharger	X	
Air temperature to and from after cooler	X	
Air pressure to and from after cooler		X
Exhaust		
Exhaust temperature out of each cylinder Cylinder No. 1 Cylinder No. 2 Etc.	X	
Exhaust temperature to turbocharger turbine (preturbine temperature), more than one thermocouple may be required	X	
Exhaust pressure to turbine[(b)]		X
Exhaust temperature from turbine	X	
Exhaust back pressure in exhaust pipe after turbine exhaust expansion section		X
Fuel Oil		
Fuel oil pressure to and from pre-day tank filter[(b)]		X
Fuel oil pressure to and from engine filter	X	
Fuel oil pressure to and from fuel oil pump	X	
Fuel oil temperature to engine		X
Fuel Pump Rack Setting		
All cylinders	X	
Miscellaneous Data		
Turbocharger R.P.M.	X	
Lube oil level in engine sump		X
Water level in expansion tank		X
Crankcase vacuum or pressure	X	
Crankcase blow-by, measure pressure drop across blow-by orifice (could use gas analysis technique)		X
Amount of oil added	X	

Parameter	Requirements	
General Data	Required	Optional
Miscellaneous Data (contd)		
Exhaust smoke color or smoke meter reading	X	
Lubricating oil analysis (quarterly recommended)		X
Engine cooling water analysis (quarterly recommended)		X
Fuel oil analysis (upon delivery recommended)		X
Number of engine starts to date	X	

(a) Note it is important that the same electrical load be used for each test (e.g., 100% of plant load).
(b) Where equipment exists.

APPENDIX B

RESUMÉS

Resumés of the two consultants used by PNL for the diesel generator research and who participated in the discussions reported in this document are presented in this appendix.

B. J. KIRKWOOD, P.E.

Covenant Engineering
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Registered Professional Engineer - CO, MO, KS, NE, IA (inactive)

Massachusetts Institute of Technology - 1950 - BS/Mechanical Engineering
- 1950 - MS/Econ & Engrg.

Member: American Society of Mechanical Engineers
Associate - Internal Combustion Engine Div. (+ 2 others)
Secretary (1967-73) Performance Test Code Com. #17, Reciprocating Internal Combustion Engines
American Solar Energy Society
National Society of Professional Engineers
Colorado Engineering Society (ex - MoSPE and KsES)
Pi Tau Sigma (national honorary ME fraternity)

1984 - present - Covenant Engineering - Self-employed consulting engineer (semi-retired)

Services include studies and consultation on: power supply planning; utility rates and economics; diesel engine applications; project administration and financing; utility coordination; and nuclear EDG applications and consultation on related regulatory concerns.

1982 - 1984 - B. J. Kirkwood, PE, Consulting Engineer (4308 W 79th Prairie Village, KS 66208) - Self-employed consulting engineer (semi-retired)

1954 - 1982 - A. C. Kirkwood and Assocs. (8080 Ward Parkway, Kansas City, MO 64114)

(A consulting engineering firm with a staff of generally 35-40, doing municipal, industrial and other governmental work in the fields of power, water, sewage, gas rates, feasibility studies, energy analyses, etc.)

Retired 1/1/82 as one of the three senior partners. Responsible for quality assurance and procedure for all specifications, studies and reports; directed all and performed many economic and rate studies; project sponsor for majority of engine-generator project designs; director of long-range planning and business analyses for Firm.

Until 1977 was Director of Administration, Participated in Client Relations, Business Development and various professional and technical matters.

NB: ACK&A was responsible (1947-1982) for probably more engine-generator installation designs than any other firm in the mid-states (the heart of smaller municipal and REC utilities), embracing at least 13 basic models of seven engine manufacturers, ranging in size from 600 to 700 kW, and speeds of 200 to 900 rpm. BJK was responsible for 15 diesel projects for 10 different clients involving 19 engines of 5 different makes. Also directed study of present and future engine utilization for the Electric Power Research Institute.

1950 - 1954	- R. R. Donnelley & Sons (Chicago) - printers - industrial engineer; purchasing agent.
Publications, ect.	- Several articles for Diesel and Gas Turbine Progress magazine; papers and presentations for Energy Technology Conference, Diesel Engine Manufacturers Association, Kansas Municipal Utilities, and Iowa Association of Municipal Utilities.

PAUL J. LOUZECKY, PE

Engineered Applications Corp
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EXPERIENCE

June 1975 to present — President of Engineered Applications Corporation, very active consulting service specializing in diesel engines, combustion engines, and related analytical services. Typical services include torsional and vibrational analysis using computer modeling, maintenance and operational problem resolution and consulting, consultant and expert witness services for the U.S. government, National Laboratories, and other engineering and private business firms. A major business area has been Nuclear Service Diesel Generator installations and related maintenance and performance consulting services.

JUNE 1970--DETROIT DIESEL ENGINE DIVISION, GENERAL MOTORS CORPORATION,
JUNE 1975 DETROIT, MICHIGAN

May 1974-May 1975 — Worked on the design and development of an 8-cylinder, vee, 4-cycle diesel truck engine, both naturally aspirated and turbocharged. Did much of the analytical and vibration design work on this engine.

Feb. 1974-May 1974 — Designed a high-pressure, high-speed fuel injection pump for use on a rotary combustion diesel engine. Each pump plunger was designed to deliver fuel 4000 times per minute.

Mar. 1973-Feb. 1974 — On loan to the Engineering Staff of General Motors Corporation to design and develop a stratified-charge automotive gasoline engine. The engine had better specific fuel consumption and lower emissions than the Honda CVCC engine.

Jan. 1971-Mar. 1973 — Supervisor in charge of the engineering and design of three rotary combustion diesel engines. Also assisted on the design and development of the rotary combustion gasoline engine.

Jun. 1970-Jan. 1971 — Executive Engineer on the MBT-70 Main Battle Tank Program reporting to the Chief Engineer. My work consisted of solving a number of vehicle-related problems, such as correcting the large number of engine (power plant) problems including cylinder block cracking, piston scuffing, engine and power plant torsional vibrations.

JULY 1963--RESEARCH LABORATORIES, GENERAL MOTORS CORPORATION,
JULY 1970 WARREN, MICHIGAN

Supervisory Research Engineer in the Mechanical Research and Special Projects Departments. In this capacity, I conducted work on a number of interesting projects which included: new, very compact locomotive engines, thermal energy storage automobile with Stirling engine (emissions free), thermal energy storage submarine engine (Stirling engine), continuous casting machine for casting many metals including steel, transportation studies, very high speed transportation systems, and fuel injection studies.

JUNE 1963--WAUKESHA BEARING COMPANY, WAUKESHA, WISCONSIN
JULY 1963

Consulting Engineer; made a market study on the potential market for internal combustion engine bearings.

MAY 1958--NORDBERG MANUFACTURING COMPANY, MILWAUKEE, WISCONSIN
JUNE 1963

Chief Engineer, Engineering, Installation and Service Departments of the Engine Division. In charge of the engineering and the administrative operation of these departments, which included all design, research, development and testing of new engines as well as improving all production two-cycle and four-cycle diesel, DUAFUEL, TRIFUEL, spark-ignition, and propane engines, both naturally aspirated and turbocharged. The work also included all installation, service and customer contact work related to these responsibilities. Supervised about 250 people.

APRIL 1935--CLEVELAND DIESEL ENGINE DIVISION, GENERAL MOTORS
MAY 1958 CORPORATION, CLEVELAND, OHIO

1955-1958 Chief Technical Engineer in Charge of Analytical Design, Vibration, Instrumentation, Engineering Welding Design, Metallurgy, Chemical Laboratory, Instruction Books, and Research and development Sections. supervised about 100 people.

1951-1955	Head of Analytical Design Section and Special Problems Section. Worked on the design of over fifty different types of internal combustion engines.
1947-1951	Supervisor of Special Problems Section. One interesting problem was the design and development of a submarine engine to run under water with a closed-loop intake and exhaust system.
1937-1947	Head of Analytical Design Section. Responsible for all stress analysis work on engine design, vibrations, governing, engine performance and electrical power plant systems.
1935-1937	Assistant in Analytical Design Section, in charge of all engine stress analysis and related work regarding the designing and development of all types of internal combustion engines and related power plant installation problems.

JAN. 1934--WEATHERHEAD COMPANY, CLEVELAND, OHIO
APRIL 1935

Assistant in Research Laboratory: developed new hydraulic equipment, very high pressure flexible hose, and automotive and aircraft fittings; hydraulic and related automotive hardware and accessories. Also developed the copper brazing technology.

JULY 1933--ELECTRIC PRODUCTS COMPANY, CLEVELAND, OHIO
JAN. 1934

Assistant Chief Draftsman: designed and developed a considerable number of specialized electrical generators, platers, welders, switchboards, motors, and other electrical machinery.

EDUCATION

1933 M.S. Mechanical Engineering, Case Western Reserve University, Cleveland, Ohio. Graduate Thesis: "Dynamic Flow Characteristics of Molten Lead.

1932 B.S. Mechanical Engineering, Case Western Reserve University

PROFESSIONAL AND TECHNICAL SOCIETY MEMBERSHIP

Registered Professional Engineer, State of Ohio (E-003068); American Society of Mechanical Engineers; Society of Automotive Engineers; Sigma Xi Honorary Science Fraternity.

TECHNICAL SOCIETY PAPERS

"Burning of Heavy Fuel in a Medium Speed, High B.M.E.P. Engine," American Society of Mechanical Engineers Paper No. 63-OGP-13, presented at O.G.P. Meeting in St. Louis, Missouri, May 19-23, 1963.

"Vibrations in River Towboats," Society of Automotive Engineers, Paper No. 699A, presented at Marine Propulsion Meeting, May 14-15, 1963, St. Louis, Missouri.

"Design and Development of a Two-Cycle Turbocharged Diesel Engine," American Society of Mechanical Engineers Paper No. 56-A-100, presented at the ASME Annual Meeting, New York, N.Y., November 25-30, 1956. Received award for Best ASME-OGP Paper presented in 1956.

PATENTS

U.S. Patent No. 2,728,331, "Engine Lubrication and Piston Cooling," December 27, 1955.

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U.S. Patent No. 3,800,179, "Self-Cleaning Spark Plug," March 26, 1974.

U.S. Patent No. 3,861,837, "Liquid Cooled Rotor Housing," January 21, 1975.

U.S. Patent No. 3,877,852, "Rotary Engine Drain Pump Arrangement," April 15, 1975.

March 1974, Pending: "Rotary Machine Apex Seal."

May 1974, Pending: "Split Phasing Gear for a Multi Rotor, Rotary Combustion Engine."

September 1974, Pending: "Rotary Combustion Engine Damped Apex Seal."

APPENDIX C

WORKSHOP AGENDA

WORKSHOP AGENDA

DIESEL GENERATOR AGING MITIGATION

Buena Vista, Colorado
April 29-30, 1987
Sumac Lodge

GOAL

To develop a fresh approach and a broad scope of all possible activities that will have a good potential to mitigate aging affects and effects related to the diesel generators.

Wednesday

8:00 am	Outline of goals, ground rules, agenda and the contractor deliverable reports.
8:20 am	Review of NUREG/CR-4590 document and the stressors identified and the problem areas. Expand the detailed workshop topical items written by K. Hoopingarner to ensure a complete scope is outlined for further discussion.
9:45 am	Break.
10:00 am	Discussion of Inspection and Testing items on the topical list in relation to mitigation and regulatory needs. Availability and reliability focus, also where required.
12:00 pm	Lunch.
1:00 pm	Discussion of Monitoring and Trending items on the topical list in relation to mitigation and regulatory needs. Availability and reliability focus, also.
3:00 pm	Break.
3:15 pm	Discussion of Modifications, Maintenance, Training and related items to mitigate aging.
5:00 pm	Adjourn.

Thursday

8:00 am	Discussion of Regulatory Guide 1.108 items and document proposed changes to match aging mitigation requirements for NRC research consideration.
10:00 am	Break.
10:15 am	Areas of future research needs, utility cooperation, and implementation needs for diesel-generator aging mitigation. If time permits, we will discuss diesel life extension.
12:00 pm	Lunch.
1:00 pm	Document workshop and ensure that all notes are complete and ready for reporting. Assign any follow up items to the contractors and PNL.

APPENDIX D

U.S. NUCLEAR REGULATORY COMMISSION, REGULATORY GUIDE 1.108

U.S. NUCLEAR REGULATORY COMMISSION

Revision 1
August 1977

REGULATORY GUIDE

OFFICE OF STANDARDS DEVELOPMENT

REGULATORY GUIDE 1.108

PERIODIC TESTING OF DIESEL GENERATOR UNITS USED AS ONSITE ELECTRIC POWER SYSTEMS AT NUCLEAR POWER PLANTS

A. INTRODUCTION

Criterion XI, "Test Control," of Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants," to 10 CFR Part 50, "Licensing of Production and Utilization Facilities," requires that a test program be established to ensure that systems and components perform satisfactorily and that the test program include operational tests during nuclear power plant operation.

Criterion 17, "Electric Power Systems," of Appendix A, "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50 requires that onsite electric power systems have sufficient independence, capacity, redundancy, and testability to perform their safety functions, assuming a single failure.

Criterion 18, "Inspection and Testing of Electric Power Systems," of Appendix A to 10 CFR Part 50 requires that electric power systems important to safety be designed to permit appropriate periodic inspection and testing to assess the continuity of the systems and the condition of their components.

This regulatory guide describes a method acceptable to the NRC staff for complying with the Commission's regulations with regard to periodic testing of diesel electric power units to ensure that the diesel electric power systems will meet their availability requirements.* The Advisory Committee on Reactor Safeguards has been consulted concerning this guide and has concurred in the regulatory position.

B. DISCUSSION

The purposes of onsite electric power systems are (1) to provide power promptly to engineered safety features if a loss of offsite power and an accident occur during the same time period and (2) to provide power to equipment needed to maintain the plant in a safe condition if an extended loss of offsite power occurs. Diesel generator units are the most common source of onsite electric power.

High reliability must be designed into the diesel generator units and maintained throughout their service lifetime by appropriate testing, maintenance, and operating programs. Branch Technical Position EICSB 2, "Diesel-Generator Reliability Qualification Testing," dated 11/24/75, of the Standard Review Plan (Appendix 7-A of NUREG-75/087[1]) establishes a reliability goal of 0.99 (at a nominal 50% confidence level) and an acceptable qualification testing program for diesel generator units of a type or size not previously used as standby emergency power sources in nuclear power plants. The preoperational and periodic testing provisions set forth in this guide have been designed to provide a basis for taking those corrective actions needed to maintain high inservice reliability of installed diesel generator units. In addition, the data developed will provide an ongoing demonstration of performance and reliability for all diesel generator units after installation and in service. Reliability objectives concerning the entire onsite electric power system's probability of failure depend on the interconnections among the system's components and are not within the scope of this guide. "Failure" is taken here to mean the failure to start, accelerate, and assume the design-rated load within and for the time prescribed during an emergency or a valid test.

*Lines indicate substantive changes from previous issue.

[1] NUREG-75/087, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants," U.S. Nuclear Regulatory Commission. Copies may be purchased from the National Technical Information Service, Springfield, Virginia 22161.

The testing of the diesel generator unit should simulate, where practicable, the parameters of operation (automatic start, load sequencing, load shedding, operation time, etc.) and environments (temperature, humidity, etc.) that would be expected if actual demand were to be placed on the system.

This guide provides design and operational provisions for the performance of periodic testing of diesel generator units used for onsite electric power for nuclear power plants. A "diesel generator unit" consists of the engine, generator, combustion air system, cooling water system up to the supply, fuel supply system, lubricating oil system, starting energy sources, autostart controls, manual controls, and diesel generator breaker.

C. REGULATORY POSITION

1. General

a. The design of a diesel generator unit should be such that it can accommodate diesel generator testing as defined in Regulatory Position C.2.

b. Diesel generator units should be designed to be testable during operation of the nuclear power plant, as well as while the plant is shut down. The design should include provisions so that the testing of the units will simulate the parameters of operation (outlined in Regulatory Position C.2) that would be expected if actual demand were to be placed on the system.

(1) Capability should be provided to test each diesel generator unit independently of redundant units. Test equipment should not cause a loss of independence between redundant diesel generator units or between diesel generator load groups.

(2) Testability should be considered in the selection and location of instrumentation sensors and critical components (e.g., governor, starting system components). Instrumentation sensors should be readily accessible and designed so that their inspection and calibration can be verified in place. Testability should be considered in selecting critical components, and the overall design should include status indication and alarm features.

(3) Periodic testing of diesel generator units should not impair the capability of the unit to supply emergency power within the required time. Where necessary, diesel generator unit design should include an emergency override of the test mode to permit response to bona fide signals.

(4) A surveillance system should be provided with remote indication in the control room as to diesel generator unit status, i.e., under test, ready-standby, lockout. A means of communication should also be provided between diesel generator unit testing locations and the main control room to ensure that the operators are cognizant of the status of the unit under test.

(5) The surveillance system should indicate which of the diesel generator protective trips is activated first in order to facilitate trouble diagnosis.

(6) All diesel generator protective trips should be in force during diesel generator unit testing.

c. Detailed step-by-step procedures should be provided for each test under Regulatory Position C.2. The procedures should identify those special arrangements or changes in normal system configuration that must be made to put the diesel generator unit under test. Jumpers and other nonstandard configurations or arrangements should not be used subsequent to initial equipment startup testing.

d. Subsequent to any failure, the cause should be determined and corrective action taken in a timely manner, with emphasis on preventing reoccurrence of the failure.

2. Testing

a. <u>Testing of diesel generator units during the plant preoperational test program and at least once every 18 months should:</u> OK

(1) Demonstrate proper startup operation by simulating loss of all a.c. voltage and demonstrate that the diesel generator unit can start automatically and attain the required voltage and frequency within acceptable limits and time. OK

(2) Demonstrate proper operation for design-accident-loading-sequence to design-load requirements and verify that voltage and frequency are maintained within required limits. OK

(3) <u>Demonstrate full-load-carrying capability for an interval of not less than 24 hours, of which 22 hours should be at a load equivalent to the continuous rating of the diesel generator and 2 hours at a load equivalent to the 2-hour rating of the diesel generator</u>. Verify that voltage and frequency requirements are maintained. The test should also verify that the cooling system functions within design limits. Recommend change to 110% of the Plant Load

(4) Demonstrate proper operation during diesel generator load shedding, including a test of the loss of the largest single load and of complete loss of load, and verify that the voltage requirements are met and that the overspeed limits are not exceeded. OK

(5) Demonstrate functional capability at full-load temperature conditions by rerunning the test phase outlined in Regulatory Positions C.2.a.(1) and (2) above immediately following (3) above.

OK, But experts see little value in this test. (5)

part d. needs reevaluation and rewording per this report focus
1. Program scope
2. Maint. action
3. Positive Monitor & Trend. results.

OK

(6) Demonstrate the ability to (a) synchronize the diesel generator unit with offsite power while the unit is connected to the emergency load, (b) transfer this load to the offsite power, (c) isolate the diesel generator unit, and (d) restore it to standby status.

OK but limit to Preop. testing

(7) Demonstrate that the engine will perform properly if switching from one fuel oil supply system to another is a part of the normal operating procedure to satisfy the 7-day storage requirement.

Reword but ok in general

(8) Demonstrate that the capability of the diesel generator unit to supply emergency power within the required time is not impaired during periodic testing under Regulatory Position C.2.c.

Limit to preoperation and no fast starts except 2. need 2e exclusion also see note 1 below

(9) Demonstrate the required reliability by means of any 69 consecutive valid tests[3] (per plant) with no failures, with a minimum of 23 or 69/n tests, whichever is the larger, per diesel generator unit (where n is equal to the number of diesel generator units of the same design and size).

OK

b. Testing of redundant diesel generator units during normal plant operation should be performed independently (nonconcurrently) to minimize common failure modes resulting from undetected interdependences among diesel generator units. However, during reliability demonstration of diesel generator units during plant preoperational testing and testing subsequent to any plant modification where diesel generator unit interdependence may have been affected or every 10 years (during a plant shutdown), whichever is the shorter, a test should be conducted in which redundant units are started simultaneously to help identify certain common failure modes undetected in single diesel generator unit tests.

c. Periodic testing of diesel generator units during normal plant operation should:

OK but time needs to be relaxed in the tech. specifications

(1) Demonstrate proper startup and verify that the required voltage and frequency are automatically attained within acceptable limits and time. This test should also verify that the components of the diesel generator unit required for automatic startup are operable.

Oil more important (LUBE. SYSTEM)

(2) Demonstrate full-load-carrying capability (continuous rating) for an interval of not less than one hour. The test should also verify that the cooling system functions within design limits. This test could be accomplished by synchronizing the generator with the offsite power and assuming a load at the ~~maximum practical rate~~. recommended rate

d. After completion of the diesel generator unit reliability demonstration under Regulatory Postition C.2.a.(9), the interval for periodic testing under Regulatory Position C.2.c (on a per diesel generator unit basis) should be no more than 31 days and should depend on demonstrated performance. If more than one failure has occurred in the last 100 tests (on a per nuclear unit basis), the test interval should be shortened in accordance with the following schedule.:

(1) If the number of failures in the last 100 valid tests is one or zero, the test interval should be not more than 31 days.

(2) If the number of failures in the last 100 valid tests is two, the test interval should be not more than 14 days.

(3) If the number of failures in the last 100 valid tests is three, the test interval should be not more than 7 days.

(4) If the number of failures in the last 100 valid tests is four or more, the test interval should be not more than 3 days.

(e) EPRI has new recommen & this report also.

e. Valid tests and failures (under Regulatory Positions C.2.a.(9) and C.2.d) should be based on the following criteria:

(1) All start attempts (automatic, including those from bona fide signals, or manual) that result in a failure to start, except as noted in (2) below, should be considered valid tests and failures.

OK

(2) Unsuccessful start and load attempts that can definitely be attributed to operating error, to spurious operation of a trip that is bypassed in the emergency operating mode, to malfunction of equipment that is not operative in the emergency operating mode (e.g., synchronizing circuitry) or is not part of the defined diesel generator unit design should not be considered valid tests or failures.

(3) Successful starts, including those initiated by bona fide signals, followed by successful loading (sequential or manual) to at least 50% of continuous rating and continued operation for at least one hour should be considered valid successful tests.

See EPRI Report

(4) Successful starts that are terminated intentionally without loading, as defined in (3) above, should not be considered valid tests or failures.

ok

(5) Successful starts followed by an unsuccessful loading attempt should be considered valid tests and failures, except as noted in (2) above.

OK But Damage needs to be defined as that which stops the emergency function not superficial damage.

(6) Tests that are terminated intentionally before completion as defined in (3) above because of an alarmed abnormal condition that would ultimately have resulted in diesel generator damage or failure should be considered valid tests and failures.

[3] Valid test as defined in Regulatory Position C.2.e.

Note 1. Limit to 12 starts with 2 fast starts per TDI study report

(7) Tests performed in the process of troubleshooting should not be considered valid tests. Tests that are performed to verify correction of the problem should be considered valid tests and successes or failures, as appropriate.

OK

(8) Cranking and venting procedures that lead to the discovery of conditions (e.g., excessive water or oil in a cylinder) that would have resulted in the failure of the diesel generator unit during test or during response to a bona fide signal should be considered a valid test and failure.

ok but maint outage tests need exemption

3. Records and Reports see note 2. below

a. All start attempts, including those from bona fide signals, should be logged. The log should describe each occurrence in sufficient detail to permit independent determination of statistical validity in accordance with Regulatory Position C.2.e. Maintenance, repair, and out-of-service-time histories, as well as cumulative maintenance and operating data, should also be logged. Cumulative statistical analyses of diesel generator unit test results, together with results of operation of the diesel generator unit when required by actual demand, should be maintained. These analyses should include examination of the trend of critical failure mechanisms, human errors, and common mode failures.

b. All diesel generator unit failures, valid or invalid, should be reported[3] consistent with the licensee's reporting requirements. This report should (1) identify the diesel generator unit involved, (2) identify the failure as being the n^{th} failure in the last 100 valid tests, (3) describe the cause of failure, (4) describe the corrective measures taken, (5) indicate the length of time the diesel generator unit was unavailable, (6) define the current surveillance test interval, and (7) verify that the test interval is in conformance with the schedule of Regulatory Position C.2.d. If the number of failures in the last 100 valid tests is seven or more, the reliability of the diesel generator units requires special evaluation, and the information provided on the report form should be supplemented, as needed, by additional narrative material that:

(1) Identifies the reported failure as the 7th or greater failure in the last 100 valid tests,

(2) Describes corrective measures, taken or planned, to increase the reliability of the generator units,

(3) Provides an assessment of the existing reliability of electric power to engineered-safety-feature equipment,

(4) Provides the licensee's basis for continued plant operation if that is planned, and

(5) Provides a summary of all tests (valid and invalid) that occurred within the time period over which the last 100 valid tests were performed, and verifies that surveillance testing during this period was in conformance with the schedule of Regulatory Position C.2.d.

Invalid failures experienced during troubleshooting should be included in the report of the failure (valid or invalid) that made the troubleshooting necessary.

[3] See Regulatory Guide 1.16, "Reporting of Operating Information."

D. IMPLEMENTATION

The purpose of this section is to provide information to applicants regarding the NRC staff's plans for using this regulatory guide.

This guide reflects current NRC staff practice. Therefore, except in those cases in which the applicant proposes an acceptable alternative method for complying with the specified portions of the Commission's regulations, the method described herein is being and will continue to be used in the evaluation of submittals for construction permit applications until this guide is revised as a result of suggestions from the public or additional staff review.

Note 2.
The scope of what should be reported is recommended to be changed per this report. Therefore, comments on reporting need to be addressed later.

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