UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

JUN 13 1989

MEMORANDUM FOR: Thomas E. Murley, Director
Office of Nuclear Reactor Regulation

FROM: Eric S. Beckjord, Director
Office of Nuclear Regulatory Research

SUBJECT: RESEARCH INFORMATION LETTER NO. 161, "RESULTS OF DIESEL GENERATOR AGING STUDY"

This Research Information Letter transmits the enclosed results of a study conducted by Battelle, Pacific Northwest Laboratories (PNL) to apply the Nuclear Plant Aging Research (NPAR) program strategy to an aging assessment of emergency diesel generators (EDG) and to the adequacy of surveillance, inspection, and maintenance methods and practices to resolve the effects of EDG aging.

The study proposed a comprehensive, but practical, approach to EDG aging management including the elements: testing, monitoring, trending, training and maintenance. The program addresses the fast-start aging stressors, proposes reliable test procedures, and takes a need-oriented approach to EDG major maintenance.

Some results from this study are already finding a place in modifications to the regulatory and industry standards, including:

- Revision of the NRC regulatory guide requirements on EDG selection, design, qualification, testing, and reliability by the Office of Research;
- Applications to standard technical specifications (Aug. 30, 1988 draft recommendations by Richard Lobel);
- Proposed revisions to IEEE Std. 387-1984 and ASME OM-16;
- Proposed IEEE guide document on aging and life extension.

This study will continue through FY 1989. PNL will review recent national and international reported EDG aging data and information to quantify and support the need to include EDG issues on license renewal.

The enclosure to this letter contains a more detailed discussion on the conclusions reached in the PNL study and resultant recommended actions to manage the aging of EDGs.

Eric S. Beckjord, Director
Office of Nuclear Regulatory Research

Enclosures: As stated

cc: W. Houston
K. Kniel

RESULTS OF DIESEL GENERATOR AGING STUDY

I. Statement of the Regulatory Issue

Regulatory issues related to Emergency Diesel Generators (EDG) have been identified and documented for diesel-generator aging and the negative influence of current fast-start testing. Additional issues are Generic Safety Issue B-56, "Diesel Reliability" and Unresolved Safety Issue A-44, "Station Blackout." Issue USI A-44 has been resolved by the release of Regulatory Guide 1.155, "Station Blackout," which outlines a reliability program as one need. A well-managed diesel-generator aging management program with appropriately structured elements should aid in resolving any safety issues that may arise in the future. This RIL addresses applicable results and recommends appropriate program elements.

II. Statement of Conclusions

It is concluded from this research that an integrated program of diesel-generator management be established. This program would integrate testing, inspections, monitoring, trending, personal training, and maintenance practices (reference Technical Evaluation Report - PNL 6287). Key elements of the program would include:

- Assurance of the diesel-generator safety function would be changed from a statistical basis of monthly fast start tests to more predictive monthly tests to monitor, trend, and predict system operability and aging degradation. Slower start tests would monitor about 50 operating parameters;

- Improve the training of maintenance and inspection personnel and provide better maintenance procedures be adopted to reduce the risk from deteriorating diesel-generator safety performance.

The utilities would generate their program and submit to the NRC for review. From utility operating submittals the NRC could monitor the diesel-generator aging degradation.

Research report NUREG/CR-4590 quantified failures and documented the aging analysis for the diesel-generator system. Utility activities should focus on the most troublesome EDG system components and the aging stressors discussed in this research report for the most effective maintenance, inspections and monitoring programs.

The research results and conclusions reported were intended to meet the objectives of the Nuclear Plant Aging Research (NPAR) Program. However, techniques identified to mitigate aging were equally effective for reliability improvement and the general resolution of other diesel-generator regulatory issues.

III. Statement of Regulatory Application

Direct recommended regulatory applications include revisions to the plant technical specifications that require periodic major engine overhauls. This requirement is not supported by the research results and data, which document increased risk of failures

following routine overhaul periods. The recommended application is to change this requirement to base major overhauls on engine condition-monitoring results or where failure correction requires it. Technical Evaluation Report, PNL-6287 documents this application.

Diesel reliabilities are based on statistical probabilities. Computer analysis show that it can require a year or more to observe changes in reliability from 98% to 92%. The probability of detecting this change is only 60% with sensitive detection criteria. Therefore it is recommended that regulatory emphasis should be directed to ensuring reliability by monthly analysis of approximately 50 performance parameters as identified in reference document PNL-6287. This recommendation is currently being included in a revision (3) to Regulatory Guide 1.9 "Selection, Design, Qualification, Testing, and Reliability of Diesel Generator Units Used on Onsite Electric Power Systems and Nuclear Power Plants", as a recommendation for an EDG Surveillance Plan.

It is also recommended that appropriate utility communications strongly encourage the utilities to dedicate a specific knowledgeable staff member to manage all significant diesel-generator safety activities such as, monitoring, inspections and test, modifications, failure resolutions, and failure closeouts.

IV. Unresolved Questions/Further Work

There are several areas of uncompleted research at this time. Some important quantification and analyses remain to be completed such as the role of common mode failures related to increased aging exposure. Other planned work involves analysis of specific plant practices and the influence of such practices on diesel-generator aging and reliability assistance on regulatory applications of the research.

All significant data gathering and analysis for the aging is to be completed in FY 1989. Application guidelines efforts are to be essentially completed in FY 1990.

ENCLOSURE

FURTHER DISCUSSION ON THE RESULTS OF DIESEL GENERATOR AGING STUDY

INTRODUCTION

This Research Information Letter transmits the results of research performed on emergency diesel-generator (EDG) aging. This research, completed under U.S. Nuclear Regulatory Commission's (NRC) Nuclear Plant Aging Research (NPAR) program, evaluated operating plant data, maintenance practices, diesel expert experience and analysis, and appropriate regulatory requirements to determine the influence of aging on nuclear plant safety. Methods and an overall program were developed to detect and manage the aging degradation processes for the diesel-generator system.

The research has applicable results and recommendations for regulatory guides and standard plant technical specifications, as well as for improved utility management and EDG maintenance practices. The essential guidelines for a comprehensive EDG management program are defined. Resolution of diesel-generator aging problems were found to be applicable to two other important current NRC issues, "Station Blackout" and "Diesel Reliability."

Recommendations are made regarding the following subjects:

new monthly testing requirements, including mitigation of "fast-start" stressors,

development of a new overall EDG program containing basic elements for utility and NRC use,

"condition monitoring" advantages and parameters needed for effective EDG trending and analysis,

role of maintenance training for aging mitigation,

basic changes to applicable standard plant technical specifications needed to improve performance,

changes to regulatory requirements to reduce engine degradation, and,

changes to specific Regulatory Guides including testing and diesel reliability.

Complete documentation of this research may be found in NUREG/CR-4590 entitled "Aging of Nuclear Station Diesel Generators: Evaluation of Operating and Expert Experience," Volumes 1 and 2, and soon to be released NUREG/CR-5057 entitled "Recommended Practice for Aging Mitigation and Improved Programs for Nuclear Service Diesel Generators." The study was performed by Pacific Northwest Laboratory for NRC's Office of Nuclear Regulatory Research.

BACKGROUND

The NRC established the Nuclear Plant Aging Research (NPAR) Program (NUREG/1144, Rev. 1) to understand and manage aging of key safety-related

equipment. Diesel generators are essential for supplying emergency power for core cooling and related needs in nuclear power plants. The general size of these engines is in the range of 5,000 to 10,000 hp or about 3,000 to 8,000kW. Each nuclear power reactor typically has two or more diesel generator units.

Diesels installed in nuclear power plants are typically tested under fast starting and loading conditions, requiring full speed, full voltage in 10 to 12 seconds and full engine load by 30 to 45 seconds. The basis of these test conditions is the response needed for the stipulated event known as the large-bore loss-of-coolant accident (LOCA). Certain requirements for this testing are specified in the technical specifications for each nuclear power plant.

The U.S. regulatory staff became aware of numerous failure-to-start problems in 1975 in diesel-generator systems. It appeared that diesel generator reliability could be improved, if assurance-of-starting was addressed. NRC Technical Report, "Diesel Generator Operating Experience at Nuclear Power Plants," 00E-ES-002, June 1975, documented the problem and formed part of the data used to develop requirements for Regulatory Guide 1.108, Revision 1, released in August 1977.

Failure-to-start problems declined as utility and NRC staff identified causes and solutions based on operating experience were implemented. However, other reliability problems, such as increasing wear and aging problems, persisted. As part of the proposed technical evaluation of USI A-44, Station Blackout, the staff on July 2, 1944 wrote a letter to all utilities stating that the requirement for EDG fast start tests from ambient could be reduced. Only one fast start from ambient would be required every 184 days (one test every 6 months). The fast start tests for the other 10 months per year would still be required; however, the diesel could be preheated and prelubricated according to manufacturer recommendation. As the utilities responded to this letter their technical specifications were revised to reflect this change in testing requirement.

The NPAR research data indicate that a significant reduction of aging effects can be achieved and long-term diesel-generator system reliability improvement can be obtained. The key to such improvement is the concurrent reduction in the fast-start stressor, the implementation of more appropriate testing, monitoring and trending procedures and some important diesel-generator maintenance program adjustments. The Phase I research has identified the diesel-generator system components that fail most often and the causes of these failures due to aging and wear.

The NPAR diesel-generator research has not been completed; however, two important areas of research have been completed to a level where this research information letter is warranted. First, the Phase I results may be used by utilities to focus maintenance attention on the systems and components with the greatest number of failures, which should yield the most effective safety improvements. All failures listed in the data used for this study were assumed to have equal safety significance, because no diesel specific probabilistic risk assessment has been performed. The NRC, especially the regional and plant onsite inspectors, may use the same information to improve audit results and thus, ensure that their public risk responsibilities are effectively discharged. Second, the Phase II preliminary results focus on aging mitigation and the elimination of certain aging stressors. These results potentially,

have direct regulatory applications to USI A-44, "Station Blackout," and GSI-B-56, "Diesel Reliability."

TECHNICAL RESULTS - NUCLEAR PLANT AGING RESEARCH PHASE I AGING STDUY

The objectives of the Phase I study were to identify and to answer these questions:

what are the important aging stressors for the diesel generator system,

what failures are occurring most often,

what subsystems and components are involved in these failures,

what fraction of the failures involve aging concerns,

are there observable aging trends, and

what are the potential corrective actions and mitigating measures for aging issues and concerns?

Significant Stressors and Failures

Important generic stressors that most affect all subsystems were identified in the Phase I study. The following are the generic stressors in order of importance showing frequency of occurrence in percentages:

vibration, thermal shock and stress, and extreme dynamic loading (27%),

manufacturing, quality control and installation errors or processing defects (18%),

environmental conditions of dust, humidity, fuel or lube oil contamination, and other normal engine room conditions (17%),

maintenance errors or omissions, which resulted in accelerated aging and eventual failure (9%),

adjustment, misalignment or calibration errors (6%), and

design and component selection or application errors (5%).

The remaining 18% were related either to miscellaneous failure causes or could not be quantified because of uncertainties in the original data or failure reports. In addition, specific aging stressors and failure mechanisms for components with high failure rates, such as the engine speed governor were identified (Hoopingarner et al. 1987).

Aging Failure Location

The data base on the aging of components includes nuclear plant data on 1,984 individual diesel generator failures in a 20-year study period from 1965 through 1984. Figure 1 shows a typical diesel-generator system boundary diagram and the percentage of aging failures associated with each of the

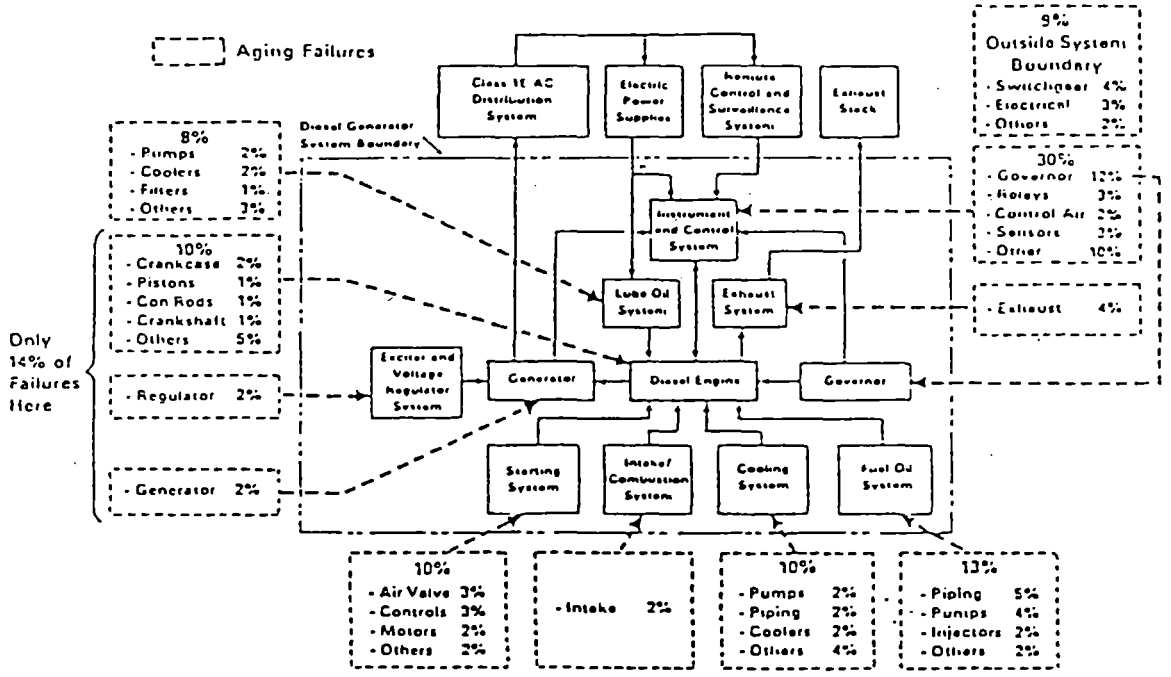

FIGURE 1. Aging Failure Percentages Associated with the Diesel Generator Systems and Components

systems and components. Maintenance attention focused on those systems with the higher failure rates should result in the greatest improvement in system reliability.

Aging Failure Trends and Analysis

The zero time point selected for measuring diesel aging was the commercial operations date. However, by that date, diesels typically have undergone several years of qualification testing and periodic testing. As a result, components in some engines with zero plant age did fail, and many of these failures were judged to be aging related or caused by maintenance induced aging mechanisms. The number of failures in the EDG data base developed by PNL are closely related to the number of operating engines. There were only 4 engines with 20 years of operation in the study period. About 185 engines had zero to one year of operation. There appears to be some overall improvement in the failure rate after the seventh year of commercial operation. After this period, the relationship between the numbers of operating engines and the failures is consistent. The ratio of aging failures to all failures appears to increase from about 45% in the zero year to about 65% in the 15th year. Because of the sampling methodology used, and because the four existing data bases used were not independent, the specific numbers of diesel failures on a plant basis for each year were not obtained in this study and were not a special concern.

TECHNICAL RESULTS - NPAR PHASE II AGING STUDY

PNL has published an important interim report addressing diesel generator testing practices and aging mitigation (Hoopingarner et al. 1988). The purpose of this report was to document an expert review group's recommendations for:

- diesel-generator testing as a part of an improved EDG management program to alleviate aging concerns due to fast starts,
- condition monitoring and trending,
- diesel generator maintenance and engine overhaul schedules,
- engine inspections,
- changes to current NRC diesel-generator regulatory requirements and Regulatory Guides, and
- recommendations to revise IEEE and ASME standards.

Aging Mitigation and Operability Improvement

The focus of the NPAR Program is to determine the causes of aging and to make recommendations to avoid or mitigate aging effects. When aging effects are corrected or avoided, there are inevitable improvements in operability safety, reliability and other benefits. Thus, this letter identifies potential benefits beyond aging-related topics and these other benefits are discussed in several later sections of this attachment.

The NPAR data indicate that a significant reduction in aging effects can be achieved and long-term diesel-generator system reliability improvement can be obtained. The key to such improvement is the concurrent reduction in the fast-start stressor, the implementation of more appropriate testing and trending procedures, and some important diesel-generator maintenance program adjustments. These three factors form the basis for the new management program recommended in this letter.

An overall program is recommended that would integrate testing, inspection, monitoring, trending, modifications, training and maintenance of the emergency power units. The recommended integrated program is similar to the program and good practices already in place at many of the small non-nuclear, diesel-powered electrical utilities. This recommended program is currently being considered in a revision to Regulatory Guide 1.9 "Selection, Design, Qualification, Testing, and Reliability of Diesel Generator Units as Onsite Electric Power Systems in Nuclear Power Plants" (Revision 3) now being reviewed. Regulatory overview of the diesel generator system should focus on how a utility's submitted program conforms to the proposed program and on how well the utility manages the program. This approach would conform to the NRC overview of other safety-related equipment. It is also recommended that the emphasis of the EDG reliability program be changed from one that analyzes statistical test data to one that monitors system operating conditions and the maintenance performed accordingly.

Improved Diesel-Generator Testing

The diesel experts consulted during the NPAR program were requested to evaluate the regulatory influence on safety related to the proposed testing

program. Fast-start testing was compared to slow-start and slow-load testing to ensure that all important safety questions were addressed. The experts concluded that the recommended slower starts adequately tested all components. A possible exception, the load sequence relays, could be electronically and electrically tested with available plant test equipment to ensure proper operation. The new testing program has several regulatory advantages such as the ability to promptly determine true engine condition, an improved statistical basis for regulatory evaluation, and improved confidence in future start and run probabilities.

Few aging effects occur in a correctly managed monthly testing program for EDGs. By contrast, the current fast-start testing requirements does have substantial aging effects. The recommended test program, including both aging and reliability concerns, should determine the true operating condition of the engine and generator system. The purpose of monthly surveillance testing should be changed from the current requirements to a new test program to obtain data on key engine and generator performance parameters. Such parameters would indicate either normal engine performance or specific indicators of an engine problem. In a well-managed test/reliability program, the problems detected in most cases will be degraded performance. If they are not managed and controlled, problems may continue on to an engine failure condition.

The recommended monthly test conditions and operating parameters are completely defined in PNL-6287 (Hoopingarner et al. 1988). About 50 test parameters which indicate real-time engine and generator condition are recommended in Appendix A of the report. It would be relatively simple to evaluate all 50 test parameters three times during each test period. The resulting 150 data points should result in high confidence in the true engine-generator condition. Most engine installations already have the local instrumentation in place needed to obtain the recommended test parameters.

A correctly managed test program should include the following:

Hardware, technical specifications, and procedures should support the ability to start the engine with a slower speed ramp designed to obtain synchronous speed in about 30 seconds. A prelube process for 2 minutes or less at full operating oil pressure before test starting is desirable.

Operation should be required at synchronous speed for 2 to 5 minutes prior to loading, while oil pressure and other important engine conditions are checked. Operation at a reduced idle speed for the same purpose should be permitted as an alternate.

Assuming that synchronous speed is achieved with no observable faults, the test program should permit gradual engine loading over a 5-to 30-minute period. Step loads representing actual site motor loads are useful but not essential for monthly testing.

After loading the system up to the plant normal emergency load, the diesel-generator should be operated until stable engine conditions are achieved before test data are obtained (about 1 hour).

Testing procedures should be defined to achieve reasonably uniform test conditions, a minimum of 3 sets of data and about one hour between data sets.

Evaluation procedures should receive an immediate data review to ensure that all test parameters are within the operational or normal range. If not, corrective maintenance should be scheduled. Long-range trending analysis may be done later. Analysis and trending should be completed on a periodic basis, but not longer than quarterly.

Engine loads should be gradually reduced at the end of the monthly test period and terminated at about 25% load or at the manufacturer's recommended load. Post-operational lubrication is recommended per manufacturer's guidelines.

After operating as recommended, optional fast-starts and additional stops and starts may be performed on a warm and well-lubricated engine with much less aging and wear effects.

Condition Monitoring and Trending

Monthly start-run testing for statistical information (Regulatory Guide 1.108 requirements) with failure reporting and maintenance is a reactive process; it gives no assurance about the future operability of engines and systems. The current statistical methods give reliability information which can be shown to lag true engine conditions by a year or more. A good overall program of testing, monitoring and trending is a proactive process that will give prompt assurance of future system operability. Such a program, often called "condition monitoring," was recommended by the diesel experts consulted during Phase II. A good diesel generator monitoring and trending program should detect many potential failures in incipient states before the component or system actually fails.

Regulatory Guide 1.108, "Periodic Testing of Diesel Generator Units Used as Onsite Electric Power Systems at Nuclear Power Plants" is currently being withdrawn. The guidance for Diesel Generator testing and reliability analysis is being incorporated into Revisions of Regulatory Guide 1.9 "Selection, Design, Qualification, Testing, and Reliability of Diesel Generator Units Used as Onsite Electric Power Systems at Nuclear Power Plants". The results of this research program are instrumental in the revision of R.G. 1.9.

Diesel-Generator Maintenance

The NPAR diesel aging research and studies have shown that improved training and better maintenance also reduce the risk of deteriorating safety performance. To avoid maintenance-induced aging stressors, PNL recommends that engine and governor maintenance training be improved. Operator training to overcome failure-to-start-and-run problems and manual starting of the engines is also perceived as a need. Two or more staff members should be given maintenance training equivalent to that offered by the diesel engine and governor manufacturers for each nuclear unit. These staff members should be at the engineering and maintenance working level. Additional training directed to systems, components, and stressors with the higher failure percentages, such as the instrument and control system and the governor, should give the best results. (See Figure 1 for the percentages.)

One important maintenance recommendation is to avoid teardown of the engines solely for the purpose of inspection. This must be done in conjunction with an adequate monitoring and trending program. Available data confirm that major engine disassembly, without specific failure correction needs, may have an adverse influence on the system failure rate. System components not

directly or indirectly monitored should continue with present maintenance procedures where risk and reliability concerns remain.

It is also recommended 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 inspections, maintenance, adjustment, and preventative maintenance based on a firm understanding (through proper training) of the governor and its service needs.

The use of failure fault diagrams with defined corrective actions for plant maintenance and operations is also 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 in a real plant emergency speeds up the process of starting the engines.

Another recommendation is that engine preventative maintenance should be increased to mitigate the aging and wear results of the vibration stressor and that the maintenance program should focus on engine or engine-skid-mounted instruments. Normal engine vibrations have a known and severe influence on control system instruments and calibration. Vibration was the diesel generator stressor found in the PNL research to cause the highest percentage of failures. Vibration cannot be eliminated, but the instrument maintenance program should address vibration through close attention to instrumentation calibration and preventative maintenance.

REGULATORY APPLICATIONS

Regulatory Guide 1.155, "Station Blackout," issued in June 1988 proposes (Section 1.2) that a reliability program be established by the licensee. The NPAR Phase II results generally support this requirement. The recommendations in this enclosure describe a reliability program that meets the needs for aging mitigation and diesel reliability.

This letter recommends a new regulatory overview consisting of a new program for assuring diesel generator operational readiness. Licensees should be required to have an approved diesel generator program following the numerous guidelines recommended in this letter. The program and its guidelines present a balanced approach where testing, inspections, monitoring and trending, training, maintenance and modifications all have appropriate importance.

The NRC should be concerned with excessive numbers of diesel-generator system failures the same as for other major safety related components, such as the high pressure safety injection pumps and motors. Licensees should report to the NRC on the basis of deviations from acceptable levels of diesel generator program performance and unsatisfactory monitoring and trending and their plans to correct such program deficiencies. The NRC overview should not be prescriptive, but rather should evaluate the licensee's maintenance, testing, inspection, monitoring and trending program for diesel generators submitted to meet regulatory guide requirements.

The fast-start aging stressor was found to be unique among all stressors found in the NPAR aging study. It is possible to minimize this stressor rather than mitigating its effects, as is the case with all of the remaining stressors. Replacing the fast-start testing with a new program, including a

slower engine test-start speed profile, should result in many benefits. The comparison of engine speed profile is illustrated in Figure 2. The direct

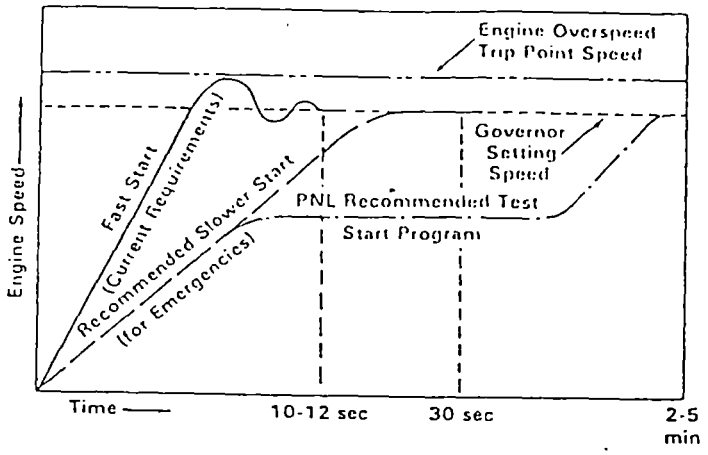

FIGURE 2. Engine Speed Profile Comparison

benefits of a slower engine speed test startup profile include significantly less ring and cylinder wear, reduced harmful overspeeds for the turbocharger and the generator, less upper cam shaft and bearing wear and less threat of an engine trip due to the initial overspeed with the currently required fast-start speed ramp.

The research results from this program have significance for the following reasons.

On July 2, 1984 a letter was written to all utilities stating proposed staff actions to improve and maintain diesel generator reliability. Here the staff has concluded that the frequency of engine fast start tests from ambient diesel generator conditions should be reduced. The results of this research program have validated this conclusion.

The recommendations from this research program generally validate and support the reliability guidance of Regulatory Guide 1.155, "Station Blackout".

The regulatory advantages of the proposed approach are:

The new diesel program is much more predictive and gives improved assurance of future engine operability compared to 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 trending and 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 utility's trending data.

Significant reduction of the severe fast-start aging and wear stressor found in combinations of plant technical specifications, equipment capabilities, and Regulatory Guide 1.108 requirements should be achieved.

Due to statistical limitations, rapid and significant performance degradation may not be detected for many months by following the statistical 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.

REFERENCES

Hoopingarner, K. R., J. W. Vause, D. A. Dingee and J. F. Nesbitt. 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.

Hoopingarner, K. R. and J. W. Vause. 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.

Hoopingarner, K. R., B. J. Kirkwood and P. J. Louzecky. 1988. Study Group Review of Nuclear Service Diesel Generator Testing and Aging Mitigation. PNL-6287, (NUREG/CR-), prepared by Pacific Northwest Laboratory for the U.S. Nuclear Regulatory Commission, Washington, D.C.