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A Review of Emergency Diesel Generator Performance at Nuclear Power Plants

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Prepared for
U.S. Nuclear Regulatory Commission

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EXECUTIVE SUMMARY

This study was performed by BNL for the NRC's Vendor Program Branch, Office of Inspection and Enforcement, in order to evaluate recent Diesel Generator (DG) and DG vendor performance. All DG vendors were reviewed with the exception of Transamerica Delaval, Inc. (TDI), due to the emphasis already being given to TDI diesels. For the time period 1980 through 1983 inclusive, BNL reviewed and evaluated DG failure data, DG vendor inspection reports, the TDI lessons learned as they related to the other vendors, and pertinent studies that had previously been completed. BNL also contacted DG vendors currently in the business to determine their present and projected work scope.

An overall conclusion is that non-TDI DG performance has been reasonably good. Considering the complexity of the DG, the overall number of failures is not excessively high in terms of failures per DG year when compared to other equipment in a power plant. Also the DG reliability figures are generally good. Additionally, losses of offsite power have been decreasing. Hence, it is not felt that an immediate, intensive inspection program of all DGs is required. Nonetheless, important areas were identified for inspection followup at DG vendors, subvendors, and nuclear power plants. The most significant areas requiring followup are: auxiliary systems components, failure analyses and corrective actions, DG maintenance, DG design modifications, and spare parts.

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1. INTRODUCTION

Emergency Diesel Generators (EDGs) are used at nuclear power plants as the major source of emergency AC power in the event of a loss of normal off-s AC power. They are also used as direct drives for some safety-related pu s such as Auxiliary Feedwater Pumps. While the goal of a reliable EDG has always been a matter of high importance to the nuclear industry, two recent developments have brought increased attention to this goal.

First, over the last couple of years diesels supplied by Transamerica Delaval Incorporated (TDI) have experienced a large number of failures, some of which were catastrophic. This naturally led to questions about the quality and integrity of diesels supplied by other manufacturers.

Second, there has been increased attention given to the situation where normal, offsite AC power is lost, calling for the operation of and increased dependence on the EDGs.

As a result, the Vendor Program Branch of the NRC's Office of Inspection and Enforcement commissioned this study to evaluate the recent (January 1980 to present) failure history of EDGs and the performance of EDG suppliers relative to NRC inspections at the vendor facilities. BNL was also requested to make recommendations as to areas where NRC should concentrate inspection activity in the next one to three years. A number of areas were reviewed in this study including: industry failure data, NRC Vendor Inspection Reports, TDI diesel generator problems, current and future diesel generator manufacturer business, and related reports and studies. During the spring of 1984, BNL also participated in several technical reviews at DG vendors. These were helpful in forming a basis for this study. Each of the areas reviewed led to general conclusions and recommendations regarding future NRC inspection focus. These are listed in each section. These recommendations from each section were then evaluated in the aggregate and prioritized in Section 5. Those areas identified in more than one section were considered more important and given more weight in Section 5. Due to the recent emphasis already given to TDI diesels by the NRC and industry, this study has concentrated on the other diesel suppliers but has utilized the knowledge and experience gained during the TDI reviews.

2. DATA REVIEW AND ANALYSIS

2.1 Review of Failure Data

The data base utilized in this study consisted of reported diesel generator failures addressed in the LER, 50.55E, Part 21, NPRDS, and EPRI document files. These files were all compiled into one computerized list by the Transamerica Delaval, Inc. (TDI) diesel generator owners' group under the title "Emergency Diesel Generator Component Tracking System." The TDI failures were separately delineated from non-TDI failures. The data analysis was performed for the period from January 1980 to January 1984 or a period of four years. Selected checks were made of the failure data in other files to verify the accuracy of the TDI owners' group compilation. No discrepancies were identified.

2.1.1 DG Component Failures

A typical diesel generator (DG) is comprised of many components including the main engine, the generator, and several secondary or auxiliary systems which support the engine. The main engine was divided into eight different components or sub-assemblies, namely: the frame, main bearings, crankshaft and torsional vibration damper, cam shaft and timing gears, cylinders, pistons, connecting rods, and cylinder heads and valves. The generator was treated as an individual component by itself. The supporting secondary systems were also categorized into components as follows: the fuel injection system, turbocharger, starting air system, speed/load control, cooling water system, lubricating oil system, fuel oil system, and Instrumentation and Control (I&C) system. Table 2.1 lists all the above components and systems. The reported failures associated with each component are summarized in the table for the Cooper, Colt, GM, and other manufacturers. TDI failures are not included.

Unlike the DGs manufactured by TDI, most main engine sub-assembly components for other suppliers exhibited no significant failures. Only a few (21 failures in 588 diesel years) engine failures related to main bearings, cylinders, connecting rods, etc. were identified. Most of these were in the Colt engines. Further study on the data and discussions with the vendor indicated inadequate pre-lube before starting for testing as the most likely cause. This could be attributable to improper maintenance activities rather than the manufacturer. Most utilities have by now corrected this practice. A total of only 21 out of 396 failures are related to the DG's main engine section.

The auxiliary systems and components have a comparatively high total number of failures (304 events). These could have resulted from poor design, manufacturing, installation, or maintenance programs. In this group, the I&C-systems have the most, followed by the lubricating oil systems, speed/load control, cooling water systems, and the starting system. In proportion to their DG years, Cooper DGs have experienced more failures in the control and monitoring systems. All other system failures are fairly evenly distributed among all manufacturers when compared with their diesel generator years of operation.

The generator related failures are found to be somewhat significant to manufacturers other than Cooper, Colt, and GM. This could include both faulty generator component design and malfunctioning generator controls. However,

there are several DG vendors involved and also several generator vendors involved; thus no clear-cut conclusion is drawn.

In order to compare the different manufacturers, the corresponding failures are normalized to their total diesel generator years (DGY) of operation in nuclear power plants. It is then found that Cooper DGs have a failure rate of 1.7 failures per DGY, followed by 0.8 for Colt, 0.5 for GM, and 0.6 for all other manufacturers. (Again note that TDI is not included in the table.) When the overall failure rate is calculated, the average failures reported are approximately 0.7 failures per DGY. Since only 7 Cooper DGs are currently in operating nuclear power plants, the high failure rate could be misleading. It is based upon only 28 DGY of operation and is judged not statistically significant. All other engines have demonstrated a fairly uniform failure rate. Reference 10 gives component failure rates for various NPP components. A review of this document shows a wide variation in failure rates among components. However, the DG failure rates listed in Table 2.1 are of the same order of magnitude as other components, especially considering the complexity of the DG.

Table 2.1 Diesel Generator Component/System Related Failures

Component No.	Component Title	Number of Reported Failures				
		Cooper	Colt	GM	Other	Total
1	Frame	-	-	-	-	-
2	Main Bearings	-	4	-	1	5
3	Crankshaft & Torsional Vibration Damper	-	-	-	-	-
4	Camshafts, Reversing System, Timing Gears, & Aux. Equip. Dr.	-	-	-	1	1
5	Cylinders	1	7	-	-	8
6	Pistons	1	0	0	0	1
7	Connecting Rods	-	3	-	1	4
8	Cylinder Heads & Valves	-	-	1	1	2
9	Fuel Injection System	4	8	1	12	25
10	Turbocharging	2	6	6	2	16
11	Starting System	3	11	16	3	33
12	Speed/Load Control	6	11	20	5	42
13	Cooling Water Systems	1	10	19	9	39
14	Lubricating Oil Systems	8	21	15	4	48
15	Fuel Oil System	1	14	4	4	23
16	I&C Systems	20	15	25	18	78
17	Generator	1	12	11	6	29
18	Miscellaneous	-	12	11	6	29
	Failure Totals	48	134	128	86	396
	No. of DGs	7	44	72	35	158
	DG Years (DGY)	28	167	244	149	588
	Failures/DGY	1.7	.8	.5	.6	.7

NOTE: In compiling these figures, no account has been taken of DG aging or wearout or of the number of demands to start on each DG.

2.1.2 System/Component Failure Modes

Table 2.2 describes typical failure modes associated with each of the DG components. It also identifies the most predominant failure modes based on a higher number of reported failures. The manufacturers with a significant number of failures in comparison to the other vendors are also included. Thus, one can qualitatively judge the problems experienced by particular manufacturers.

As mentioned earlier, Colt DGs are found to exhibit relatively high failures in the main engine components, although the total failures attributed to these is not significant when compared to TDI DGs. The predominant failure modes appear to be maintenance-related, and therefore, could possibly have been avoided with a better applied maintenance program.

With the exception of the I&C systems and the speed/load control systems, most failures in other auxiliary systems have indicated the leaking of air, water, or fuel as one of the predominant modes. Sometimes these are attributable to leaking seals and gaskets, which could be caused by wear during their service life or by their improper installation at the time of regular maintenance. Most valve or fitting failures and the cracking of tubes and pipings have also caused leaking of the fluid or air from the system leading to a failure.

Noise/Vibration related failures can be caused by improper or insufficient anchoring, broken hardware, linkage bindings or excessive engine vibration. Each of the above causes could result from maintenance errors at the time of routine checking, wear, or corrosion of metal components.

In addition to the auxiliary systems failures, the following components and subcomponents (a number of which are manufactured by various subvendors) are found to contribute significantly to DG failures:

- fuel injection pumps
- valves and fittings
- compressors
- air-start motors
- Woodward governors
- heat exchangers
- heaters
- pressure switches and gauges
- solenoid valves and control switches
- circuit breakers and relays
- generators

Failure causes associated with some of the above components are discussed later in this section.

Many control related failures are due to: relay, breaker, or switch trips, and to malfunction of pressure gauges and switches. Personnel and design logic errors and mis-adjustments of settings have also caused a number of the reported failures. GM diesels have experienced the most failures (25) from I&C malfunctions. I&C failures of Cooper diesels are also significant (20), based on their small population found in nuclear industry.

Table 2.2 DG Component Failure Modes

Comp. No.	Component (Total Failures)	Failure Modes	No. of Failures	Mfrs. w/ Significant Failures
1	Frame (0)			
2	Main Bearings (5)	Wear	2	
		Inadequate Lube	2	Colt - 4
		Foreign Particles	1	
3	Crankshaft (0)			
4	Camshaft, Timing Gears, etc. (1)	Coupling Bolting	1	
5	Cylinders (8)	Scoring	2	
		Seal Leaks	6	Colt - 7
6	Pistons (1)	Seizure	1	
7	Connecting Rods (4)	Loose Bolts	2	
		Cracks	1	Colt - 3
		Bearing Failure	1	
8	Cylinder Heads & Valves (2)	Valve Timing	1	
		Valve Leaks	1	
9	Fuel Injection System (25)	Pump Seizure	3	Others - 12
		Oil Leaks	12	Colt - 8
		Linkage Binding	7	Cooper - 4
		Belt Failures	3	
10	Turbocharging (16)	Noise/Vibration	6	
		Leaks	2	Colt - 6
		Broken Belt	3	GM - 6
		Misc. (including pers. error)	5	
11	Starting System (33)	Air Leak	7	
		Sticking	2	GM - 16
		Design Logic Error	2	Colt - 11
		Valves Malfunction	3	Cooper - 3
		Compressor Related	4	Others - 3
		Airstart Motor	8	
		Wear & clogging (from loose parts, dirt, etc.)	7	
12	Speed/Load Control (42)	Loose or Broken Pts	8	GM - 20
		Misadjustments	5	Colt - 11
		Woodward Governor	29	Cooper - 6 Others - 5

Table 2.2 (Continued)

Comp. No.	Component (Total Failures)	Failure Modes	No. of Failures	Mfrs. w/ Significant Failures
13	Cooling Water Systems (39)	Jacket Water Pump	9	
		Valve Leak or Fail.	6	GM - 19
		Piping Leak or Plugged	13	Colt - 10
				Others - 9
		HX Tube Failures	9	
		Personnel Errors	2	
14	Lubricating Oil Systems (48)	Pump Failures	8	
		High Crankcase Press	8	
		Lube Oil Heating	5	Colt - 21
		Heat Exchanger Leak	10	GM - 15
		Filter, Tubings, Oil Contamination	13	Cooper - 8
				Others - 4
		Pressure Switch Malfunction	4	
15	Fuel Oil System (23)	Fuel Oil Contamin.	5	
		Leaking Piping/ Gasket	5	Colt - 14
		Valves (leak, bind.)	12	GM - 4
		Personnel Error	1	Others - 4
16	I&C Systems (78)	Relays Trips	19	
		Circuit Brkrs Trips	7	GM - 25
		Press. Gauges & Switches, Wires	17	Cooper - 20
				Others - 18
		Solenoid Valves	8	Colt - 15
		Piping, Tubing, Fittings	4	
		Engine Shutdown Ctrl	12	
		Personnel Error	11	
17	Generator (42)	Generator-related	16	Other - 19
		Generator Control	23	Colt - 12
		Others	3	GM - 10
18	Miscellaneous (29)	DG Trip	16	Colt - 12
		Others	13	GM - 11
				Others - 6

2.1.3 Typical Component Failure Causes

Some components experiencing higher failure rates were further studied to identify the problem areas for future improvements. An attempt was made to associate these failed components with their individual manufacturers, so that the NRC could establish an audit program for these in addition to the DG vendors. However, with the one exception of Woodward governors, the failure documents reviewed were not detailed enough to provide any sub-vendor information. In the few cases where the subvendors were identified, there exists no apparent indication of frequent failures of their components.

Typical failure causes are listed below for each of several failure modes and components:

1. Fuel Oil/Lube Oil/Turbocharger Air Related Failures

   - gaskets, seals, or O-ring leaks
   - improper fittings or accessories
   - broken/cracked lines, tubes, or hoses
   - plugs missing
   - pump seal leaks
   - valve seat leaks
   - eroded caps or plugs
   - clogged/dirty strainers
   - loose connections
   - heat exchanger tube failures
   - contamination
   - improper fluid level

2. Noise/Vibration Related Failures

   - pump or fan seizure due to broken vanes or impellers
   - sheared or failed bolts (hardware)
   - unbalanced components
   - loose fittings or hardware
   - improper lubrication of bearings

3. Control System Failures

   - tripped relays

     - blocked components
     - rust/scale deposits
     - loose screws
     - faulty component
     - out of calibration
     - oxidation of contacts
     - vibration induced
     - quick restart (within required delay time)

- circuit breaker/switch trips

  - burned out fuses
  - faulty design
  - auxiliary contacts
  - vibration
  - high crankcase pressure
  - wrong set points
  - voltage spikes

- solenoid valve failures

  - out of adjustment
  - bent plungers or discs
  - moisture inside the valve
  - solenoid leak
  - deformation due to heat and pressure
  - coil failure

- pressure gauge/switch, tubing, terminal board failures

  - out of calibration due to vibration
  - defective components
  - broken wire
  - air leak
  - grounded
  - capacitor failures
  - blown fuse
  - dirty contacts
  - logic errors

4. Generator Failures

- generator proper

  - undersized exciter
  - brush-holder loose or out of place
  - damaged slip rings
  - insufficient cooling air flow
  - relay trip due to broken slip ring
  - loose pole wedges
  - trip due to voltage spikes
  - faulty design
  - bearing insulation degraded

- generator control system

  - restart within delay period
  - blown fuse
  - defective designs
  - inverter failure
  - burned relay switch
  - dirty contacts
  - burned SCR, resistors, electrical coils

5. Governor Related Failures

- Woodward Governor Co. (WGC)

  - rubbing from pointer disc
  - shutdown solenoid plunger stuck (3)
  - bad solder connection
  - synchronous speed setting wrong
  - high speed limit switch failed
  - burned resistor in power supply (4)
  - motor for potentiometer failed
  - wear
  - needle valve out of adjustment
  - loose connection
  - drift
  - dirt or air in oil (4)
  - bent rod
  - failed booster servo
  - low oil level (no procedure to check level)
  - bad fuse (2)
  - failure mode unspecified, sent back to manufacturer (4)

There have been 29 failures of Woodward Governors. This is the largest number for any subcomponent in the DG and indicates a problem that merits followup at Woodward by the NRC. There is no dominant mode of failure (17 different modes in 29 failures). Thus, this high number of failures could possibly be due to the complexity of the subcomponent. Additionally, Woodward has indicated that they do not meet 10 CFR 50 Appendix B and Part 21. This has been accepted by NRC*, and the burden of ensuring the parts are suitable, qualified, and dedicated has fallen on the DG vendors and utilities. It is not clear that the vendors and utilities have done all that they should as a result of this. NRC should re-evaluate the situation of WGC's compliance with Appendix B and Part 21, the use of WGs in the majority of DGs, and the appropriateness of actions taken by utilities, DG vendors, and WGC to respond to failures (e.g., failure analyses, corrective action, and preventive action).

2.1.4 Failure Detection Method and System Status

The NPRDS Annual Report of Cumulative Component Reliability for the period July 1974 to December 1982 contains 96 DG units which have reported 218 failures (Table 2.3 has been extracted from that report and is included here for information). A large number of these belong to engines with 1000-5000 HP units. Of all failures, 134 were detected during surveillance and 33 additional failures by operational abnormality. Most failures occurred while the system was either in service or test and therefore were detected immediately.

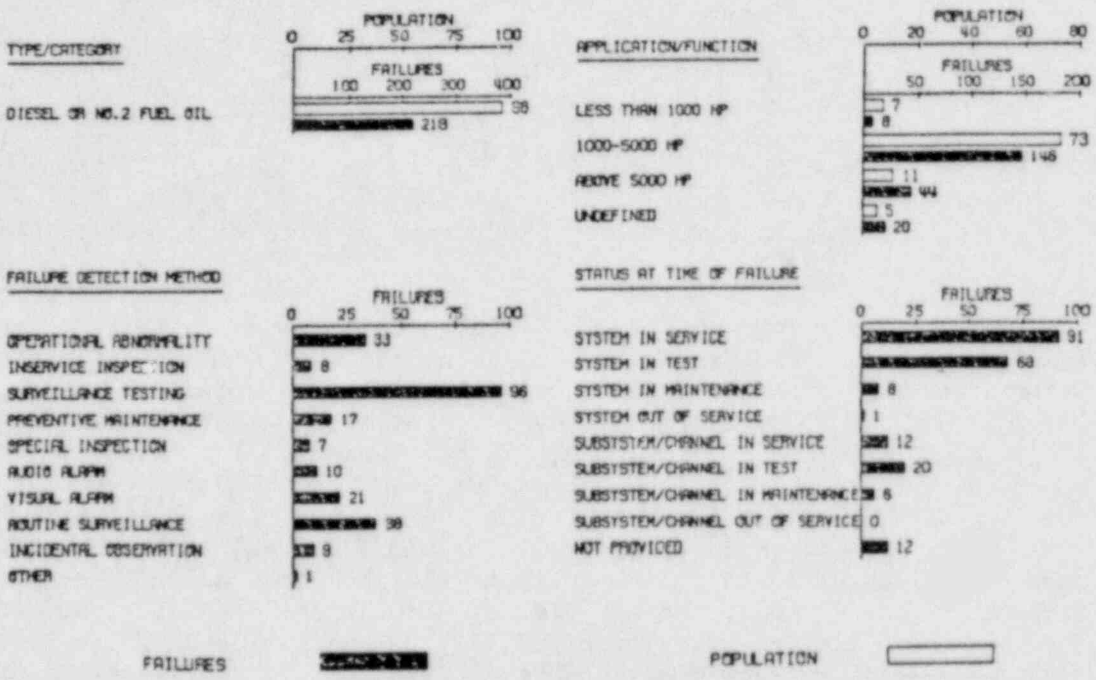
*Letter from NRC TO Woodward Governor Co. dated 10/08/82.

Table 2.3 NPRDS Annual Report of Cumulative Component Reliability

PERIOD: 7/74 - 12/82 NUCLEAR PLANT RELIABILITY DATA SYSTEM

THIS REPORT CONTAINS STATISTICS ON ALL COMPONENTS IN THE NPRDS ACCUMULATED BETWEEN 7/1/74 THRU 12/31/82

COMPONENT CLASSIFICATION : ALL FAILURE MODES	COMP IN CATEGORY	CALENDAR HOURS(MIL)	NUMBER OF FAILURES	OUT-OF-SERVICE HOURS HIGHEST	AVERAGE	LOWEST
ENGINES, INTERNAL COMBUSTION	96	11.675	218	7560	199	0



2.1.5 Summary

As discussed in the preceding sections, non-TDI Diesel Generator failure records from January 1980 through the end of December 1983 were reviewed. As a result of this review, it is concluded that:

1. The overall number of failures and the failure rate (failures per DG year) do not appear excessive.

2. Failures in main engine components are particularly low.

3. Diesel Generator auxiliary systems have a comparatively high failure rate.

4. Woodward Governor Co. is the only component subvendor that stands out with a high failure rate.

5. Repetitive failures were noted in a number of areas.

As a result the NRC vendor inspections should emphasize the following areas:

At the DG vendors:

- Auxiliary Systems Components
- corrective actions for failures
- failure analysis
- Part 21 evaluations

At NPPs:

- Auxiliary Systems Components
- corrective action for failures
- Maintenance and Training.

2.2 Review of Vendor Program Branch Inspection Reports

2.2.1 Introduction

Under the NRC licensing and inspection program the licensee is responsible for the proper construction and safe operation of nuclear power plants. The total government-industry system for the inspection of nuclear facilities has been designed to provide for multiple levels of inspection and verification. Licensees, contractors, and vendors each participate in a quality verification process in accordance with NRC rules and regulations. The NRC inspects to determine whether its requirements are being met by a licensee and his contractors, while the great bulk of the inspection activity is performed by the industry.

Firms designing nuclear steam supply systems, architect engineering firms doing design work on nuclear power plants, and certain selected vendors are currently inspected on a regular basis by the NRC. NRC inspectors, during periodic inspections, ascertain through direct observation of selected activities (including review of processes and selected hardware, discussions with employees, and selected record review) whether a licensee or contractor is satisfactorily implementing their QA program.

NRC also conducts reactive inspections to verify that vendors have taken appropriate corrective/preventive measures, when defects or conditions which could adversely affect the safe operation of such facilities are identified, and to verify that these organizations are complying with the NRC requirements which govern the evaluation and reporting of such conditions.

Included in the vendors that the NRC Vendor Program Branch (VPB) has inspected over the years are five DG suppliers. Their inspection reports were reviewed to determine the effectiveness of NRC inspection coverage and to identify any recurrent trends or problem areas at the DG vendors. Inspection reports are published quarterly (Ref. 1).

2.2.2 Report Review

The NRC-VPB has inspected the four non-TDI DG suppliers in the past five years as follows:

Colt/Fairbanks-Morse	6 times
Morrison-Knudsen	4 times
Cooper	3 times
Stewart & Stevenson	1 time

Each inspection report was reviewed to identify the number and type of findings. Findings included violations, deviations, nonconformances, unresolved items, and comments. These findings were then categorized as to the general area in which they fell. It was determined that 14 areas were needed to properly sort the findings. Some of the findings were judged to be particul rly significant and were counted separately to aid in the evaluation. The areas utilized for the sort are as follows:

P21 pass on	- Not correctly passing on Part 21 requirements to subvendors
P21 Admin	- Administrative requirements of Part 21
P21 Eval	- Improper evaluations of failures under Part 21
P/W	- Paperwork findings
DCC	- Design Change Control
QA	- Broad Quality Assurance Program Findings (not QC)
Proced.	- Improper following of procedures
Procur.	- Procurement practices
P. C.	- Manufacturing Process Control
Test	- Testing of Products
Cust. FB.	- Feedback of information to customers
T & Q	- Training and Qualification
Hardw.	- Hardware findings
Prog.	- Broad programmatic findings

Table 2.4 illustrates the total distribution of findings and Table 2.5 gives the distribution of only the significant findings. After serious consideration, it was decided that computations of average number of findings per year, per inspection, per inspecto /, etc. were not valuable or useful. Thus, conclusions are made subject y using engineering judgement on the number and significance of the findi without normalizing.

2.2.3 Conclusions

Based on the review and analysis of the VPB inspection reports, the following general conclusions are made:

1. Due to the significance, the number, and the broad distribution of findings it is considered there has generally been good overall coverage of diesel vendors.

2. There is a large number of paperwork findings which are not particularly significant.

3. Considering the number of inspections, amount of diesel business, and significance of findings, Cooper and Morrison-Knudsen had proportion-

Table 2.4 Summary of All Inspection Findings (1980 - 1984)

Category / Plant	P21 Pass On	P21 Admin.	P21 Eval.	P/W	DCC	QA	Proced.	Proc.	Poc.	Test	Cust. F/B	T&Q	Hardw.	Prog.	Total
Cooper		2	2	5	3	4	3	5	1			1	1		27
S.S.		1		3	1				3			1		2	11
Colt		2	1	19	4	2	1	1		4	1				35
M.K.	1	2	1	8	4	1	1	2	2	1		3			26
TOTAL	1	7	4	35	12	7	5	8	5	5	1	5	1	2	99

Table 2.5 Summary of Significant Inspection Findings (1980 -1984)

Category / Plant	P21 Pass On	P21 Admin.	P21 Eval.	P/W	DCC	QA	Proced.	Proc.	Poc.	Test	Cust. F/B	T&Q	Hardw.	Prog.	Total
Cooper			1		2	1		1					1		6
S.S.														2	2
Colt			1		1	1				2	1				6
M.K.	1		1		2	1				1					6
TOTAL	1		3		5	3		1		3	1		1	2	20

ally more findings than Colt and Stewart & Stevenson (but not nearly as many as TDI).

4. In addition to paperwork and quality assurance, the vendor inspections often looked at actual problems based on failure reports from plant sites (e.g. Part 21, LER, and 50.55e reports). These focus the inspections into important areas where failures are occurring. NRC inspection into these areas helps ensure vendors are giving proper attention to the failures, failure analysis, and corrective actions. It is important to continue this type of review, even though it does not generate a large number of regulatory findings. Even though it is an important area, the paucity of findings is because it is more difficult to write a nonconformance against hardware/engineering/corrective actions than against paperwork or quality assurance. Nonetheless, it is still important to continue inspections in these areas.

5. When component failures (DG or otherwise) occur at nuclear sites, utilities quite often do not notify the component vendor. The utility may report the failure to the NRC, but neither the utility nor the NRC may be aware of the generic implications of the failure. On the other hand, the vendor is sometimes in the best position to know this, since he knows to whom he has supplied the components. Unless the vendor is informed of the failure or deviation, however, he cannot fulfill his evaluation or reporting obligations under Part 21. Without this vendor evaluation and reporting, the NRC and the industry are missing a significant input to improving safety. BNL therefore recommends that the NRC have utilities provide the pertinent vendor with copies of 50.55e reports, LERs, and Part 21 reports. The vendor can then perform his required Part 21 evaluation and notify the NRC of other facilities affected by the failure/deviation. The mechanism of having utilities do this could be via a Bulletin, Information Notice, letter, rule change, or informal verbal request as determined appropriate.

6. The breakdown as to which components of a DG set are required to meet the ASME code and which are not required to meet the ASME code is specified by the Architect/Engineer (AE) or utility in the purchase specification. The nominal breakdown is that the main engine parts are not code parts, while auxiliary components such as cooling water and lube oil are code parts. The actual breakdown was noted to be very arbitrary and varied even between identical DGs at a given manufacturer, due to the AE's specification. There was noted to be no guidance as to where the breakdown should be, either in the ASME Code or in NRC guidance documents. This area should receive further NRC review.

Based on the past problems identified, as summarized in the two tables above, the following recommendations are made for future DG vendor inspections.

1. Continue reviews of failure reports and the related Part 21 Evaluation System.

2. Review Design Change control systems and actual implementation.

3. Examine the procurement system, particularly as it relates to spare parts.

4. If any testing of an ongoing nature is being performed, this should be reviewed carefully, including test procedure review, test witnessing, and test results evaluation.

5. When significant problems are identified at a vendor during an inspection, the root causes should be determined and the QA system reviewed to identify why it did not prevent/correct the problem.

2.3 Review of TDI Failures

Although this study has concentrated on vendors other than Transamerical Delaval, Inc. (TDI), the TDI experience has been reviewed to determine any potential implications on the non-TDI vendors. Over the time period 1980 to 1983 numerous failures occurred in DGs supplied by TDI. These problems included:

broken crankshafts
cracked cylinder heads
excessive turbocharger thrust bearing wear
piston modifications
jacket water pump failures
numerous bolting & capscrew failures
lube and fuel oil leaks
pneumatic logic errors
fuel injection line failure and fire
connecting rod and main bearing failures
push rod cracks
cracks in piston skirts
cracked bedplates
miscellaneous auxiliary equipment failures

The nuclear utilities owning TDI DGs have formed an owners group and the NRC a special task force who are performing many tests, modifications, analyses, and reviews of all the various problems and the overall TDI DG design. BNL has reviewed the various TDI documents and held discussions with members of the owner's group and the NRC task force and consultants, with the objective of determining what aspects of the TDI problems may be generic to other DG vendors.

The NRC TDI Task Force believes that the following items identified during their reviews are generic or merit followup, time permitting, at other DG Vendors/Nuclear Power Plants:

1. Quality Control on replacement parts.

2. Torsional analyses of crankshafts, specifically:

   - What type analysis was performed and is it adequate?
   - What are the DG critical speeds and are they passed through on startup or operated nearby?

3. DG Power Ratings: Has the power rating of any DGs been increased? If so, has adequate retesting been performed?

4. Inadequate torquing: Adequate specifications by vendor engineering and implementation by vendor and NPP.

5. Modifications: The question of whether manufacturer modifications are design improvements or required backfits and whether customers are properly notified.

6. Failures: Vendor service records of field failures.

7. Vendor internal "No Charge" accounts: These should delegate responsibility within the company for field failures that the vendor has accepted responsibility for, from customers.

It is also felt that failure and repair records as well as design modification records should be reviewed at nuclear power plants.

2.4 Effectiveness of VPB Effort

In order to evaluate the effectiveness of the NRC Vendor Program Branch (VPB) in their inspection of DG vendors a number of items need be considered including: the timing of actual work vs. VPB inspections, the actual quality of vendor work performed, the type and quality of inspections performed, and the followup by the NRC on adverse findings of the inspections.

Inspection of DG vendors by the NRC-VPB began in the late seventies and continued fairly consistently through the eighties. However, by the time these inspections were well underway, the large majority of all nuclear power plant EDGs had been fabricated and shipped to the nuclear plants. Thus, while some DGs were still being built while the inspections took place, the large majority were not. Hence, any improvements caused by the inspections would not affect most DGs (with the possible exception of design changes). Also, the quality of DGs previously delivered was not very inspectable at the vendor facility. In general, this could only be inferred through current practices and past records.

NRC inspections have tended to focus on paperwork and quality aspects of programs that enhance an already good product. They generally do not go into detail to directly determine the actual quality of the hardware in a product. In fact, the hardware quality is a very difficult thing for any outside entity to determine, particularly when such a variety of complex products are inspected, as does the NRC-VPB.

TDI Diesel Generators have had significant problems, as noted in Section 2.3 above. Also, the VPB inspection at TDI identified a significant number of findings. However, an evaluation of the effectiveness of the Vendor Program Branch relative to TDI is beyond the scope of this study. With regard to the other DG manufacturers, the failure history and the inspection record are noticeably better than they were for TDI. Also the inspection findings were generally followed up to their resolution. Thus, considering the unavoidable difficulties mentioned above, it is concluded that for DG vendors other than TDI, the VPB inspection program was reasonably effective in ensuring and enhancing the quality of the product.

3. MANUFACTURERS

3.1 List of Suppliers

The following list of DG manufacturers vs. nuclear plant sites was constructed from a number of references, including Reference 2, plant FSARs, and DG vendor information. Some of the information in the literature is contradictory, and resolutions were made as best as possible without contacting each site for confirmation. General Motors Co./Electro-Motive Division DGs were not supplied directly to any nuclear site but rather through a supplier or packager. For a number of early plants with GM diesels, it was not possible to determine the supplier without calls to the sites. Some plants appear more than once since they have DGs onsite by more than one vendor.

Table 3.1 Diesel Generator Manufacturers vs. Site

ALCO

Diablo Canyon 1/2
Ginna
Indian Pt. 2/3
Palisades
Pilgrim
Salem 1/2

ALLIS CHALMERS

LaCrosse

CATERPILLAR

Big Rock Point
LaCrosse
Ft. St. Vrain

COOPER ENERGY SERVICES

Braidwood 1/2
Byron 1/2
Cooper
Nine Mile Point 2
Palo Verde 1/2/3
South Texas 1/2
Susquehanna 1/2
Waterford 3
Zion 1/2

NORDBERG

Brunswick 1/2
McGuire 1/2

WORTHINGTON

Cook 1/2

DELAVAL

Bellefonte 1/2
Catawba 1/2
Comanche Peak 1/2
Grand Gulf 1/2
Midland 1/2
Perry 1/2
Rancho Seco
River Bend 1/2
San Onofre 1
Shearon Harris 1/2
Shoreham
Vogtle 1/2
Yellow Creek 1/2

COLT/FAIRBANKS MORSE

ANO 2
Beaver Valley 2
Callaway 1
Calvert Cliffs 1/2
Crystal River 3
Duane Arnold
Farley 1/2
Fermi 2
Hatch 1/2
Hope Creek 1
Limerick 1/2
Millstone 1/2/3
North Anna 1/2
Peach Bottom 2/3
Robinson 2
Seabrook 1/2
Shoreham
Summer
Three Mile Island 1/2
Vermont Yankee
Wolf Creek 1

Table 3.1 (Continued)

NONE

Oconee 1/2/3 (Hydro plant)

GENERAL MOTORS/EMD THRU SUPPLIERS

SUPPLIER UNKNOWN (GM/EMD)

Beaver Valley 1
Fort Calhoun
Haddam Neck
Kewaunee
Maine Yankee
Monticello
Nine Mile Point 1
Oyster Creek
Point Beach 1/2
Rancho Seco
Saint Lucie 1
Surrey 1/2
Turkey Point 3/4
Yankee Rowe

STEWART & STEVENSON (GM/EMD)

ANO 1
Braidwood (Detroit Diesel)
Byron (Detroit Diesel)
Clinton
LaSalle 1/2
Nine Mile Point 2
Perry
River Bend
San Onofre 2/3
WNP 2

MORRISON-KNUDSEN (GM/EMD)*

Brown's Ferry 1/2/3
Davis Besse
Grand Gulf (HPCS)
Hartsville A1 & A2
Saint Lucie 2
Sequoyah 1/2
Watts Bar
Susquehanna (Cooper Diesel)

BRUCE (GM/EMD)

Trojan
Fitzpatrick

WESTERN ENGINE (GM/EMD)

Dresden 2/3
Quad Cities 1/2

* One diesel for Susquehanna was manufactured at Cooper and then sent to M-K for final assembly and testing. All other D/Gs listed here were GM diesels supplied to plants through M-K.

3.2 Future Projected DG Vendor Activity

Phone interviews were conducted with five nuclear DG vendors in order to determine the extent of their current nuclear related work, as well as a projection for nuclear business over the next one to three years. The vendors contacted were: Alco Power, Inc., Cooper Energy Services, Fairbanks Morse Engine Division of Colt Industries, Morrison-Knudsen, Inc. (Power Systems Division), and Stewart & Stevenson Services, Inc. All were very cooperative and provided good information.

With the exception of one or two DGs, all nuclear DGs have been completed by the vendors and shipped to the sites. There are only a few prospects for new full DG orders. These prospects are: new nuclear plant orders (not foreseen), replacement DGs for plants with TDI diesels (possibility), and spare DGs for the nuclear plant Pooled Inventory Management Systems (probability).

All DG suppliers, however, are supplying various other kinds of hardware and services to nuclear plants. Each projects that this type of work will continue for at least the next 3 years. The types of businesses involved are:

- spare parts
- upgrades or retrofits shipped as units for installation in the field
- field service contracts (for modifications, maintenance, operation, or failure analysis)
- engineering services
- training
- diesel generator qualification testing

In light of the above projected business, it is judged that the most pertinent areas for NRC inspection would be:

<u>At the DG Vendors</u>:

- spare parts supply system*
- failure analysis*
- design change control and implementation*
- procurement
- training
- operational recommendations

<u>At NPPs</u>:

- maintenance*
- training*
- operations
- spare parts
- procurement
- failure analysis
- design change control

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* Denotes those inspection areas judged to be most productive.

One area of particular note that requires special attention by the NRC is when former nuclear grade vendors continue to supply spare parts, but supply them only as commercial grade. In some cases parts are engineered to a specification and are not catalogue items, yet the vendor does not maintain an Appendix B QA program or a 10 CFR Part 21 program. Similar to this is the general question of non-nuclear qualified vendors supplying commercial grade spare parts and services to nuclear plants. Some DG vendors and subvendors are in this category (e.g., Stewart & Stevenson and Woodward Governor). It is not clear what the responsibilities of the prime vendor and the utility are, and it appears that many utilities have not taken additional special precautions as would be required. This situation will become more common over the next several years in many equipment areas.

4. PREVIOUS RELATED STUDIES

A survey was made of the literature to determine any related reviews or studies that had been performed. The most pertinent ones were reviewed and are listed in the references. Some are still relevant to DG construction, operation, maintenance and to this study, and hence are discussed below.

4.1 NUREG/CR-0660 (Reference 2)

This study is very detailed and makes a number of recommendations for DG operability, which were endorsed by the NRC, when issued, and again recently in Generic Letter 84-15, as discussed below. The recommendations of this study are still considered applicable and are summarized here for convenience:

I Most Significant Recommendations

1. Add air driers in Starting Air Systems.
2. Ensure DG room air quality and protect relays from dust and dirt.
3. Add heavy duty turbocharger gear drive.
4. Train all DG related personnel.

II Significant Recommendations

1. Ensure pre-lubrication of DGs.
2. Testing: Minimize no-load operation, follow manufacturer's guidelines, improve preventive maintenance, final check-off test after work on DG.
3. Root cause and corrective action systems - improve.

III Additional Recommendations

1. DG ventilation: Use outside air for combustion, filter room ventilation air, do not allow air to recirculate.
2. Fuel Storage: Add water drain in fuel tanks, modify fuel supply pump power supply.
3. Add high temperature insulation for generator.
4. Engine cooling water temperature control - use 3-way thermostatic valve.
5. Paint concrete floors.
6. Review pertinent documents.
7. Review and consider implementing all the above recommendations.

4.2 NSAC-79 (Reference 6)

The study, sponsored by the Nuclear Safety Analysis Center for the Electric Power Research Institute, determines steps that plants may take to improve DG reliability, particularly Colt and GM diesels. The study reached three main conclusions and had findings in several additional areas. The three main conclusions were:

1. Plants should implement a well-documented, comprehensive, preventive maintenance program for their DGs.
2. Plants should continuously lubricate main and turbocharger bearings.
3. Plants should also continuously heat lube oil and coolant water.

Additional findings/recommendations were:

1. There was noted to be a wide variation in DG maintenance programs.
2. Thorough training of DG maintenance personnel is necessary.
3. Verify that Colt Opposed-Piston Model Engines have the continuous lubrication backfit.
4. Verify that the special nuclear maintenance program for nuclear Colt DGs is being implemented at each Colt site.
5. Verify that problems created by third party purchase of GM/EMD diesels are properly handled at GM sites (e.g., training, information transfer, and modifications).
6. Plants should review recommendations of document plus example test procedures and maintenance programs.

In summary, this document supports the need for emphasis on DG maintenance, training and Design Change Control.

4.3 NSAC-80 (Reference 7)

This document analyzes all losses of offsite power at U.S. Nuclear Power Plants. It gives insight into the usage that could be required of emergency power DGs. It also concludes that offsite power systems reliability has been increasing recently, due to a number of reasons explained in the document. For all years up to, but not including, 1981, loss of offsite power occurred 0.112 times per site per year. For 1981 through 1983 inclusive, the number is 0.027 times per site per year. This information indicates that the actual demand for DGs is decreasing.

4.4 NRC Generic Letter 84-15 (Reference 5)

This letter was sent to all nuclear utilities due to concerns about DG reliability. It had three main facets:

1. Utilities should reduce the number of cold fast starts.
2. Utilities were requested to supply reliability data for their DGs.
3. Utilities were requested to describe their DG reliability program (if any).

Replies have been received by the NRC from the majority of licensees. The responses to items 1 and 2 have been preliminarily reviewed by NRC and item 3 responses will be reviewed over the next several months. From the responses, it appears that most licensees have implemented pre-lubrication systems or procedures, such that very few are performing cold starts. From the reliability data furnished, the large majority of DGs have reliabilities greater than 0.95; a few between 0.90 and 0.95; and only one plant had DG reliability below 0.90. Overall, this reliability data is considered good, and when combined with the decreasing instances of loss of offsite power, it tempers the need for an immediate major NRC inspection effort in the DG area.

5. RECOMMENDATIONS

These recommendations are synthesized from the conclusions and recommendations in the preceding sections. Where particular areas were indicated for inspection in more than section due to multiple reasons, they are given higher priority here in the recommendations section. In order to perform effective review and inspections of DGs and DG vendors, it is clear that inspections must be performed at both the vendor facilities and the nuclear plant sites where DGs are used. In order to maximize the effectiveness of the inspection effort, these inspections should be coordinated. Hence, recommendations are given below for areas to review at both the DG vendors and at the nuclear power plants where DGs are used. In order to obtain more detail and better understand specific recommendations, the reader should refer to the main body of the report.

5.1 DG Vendor Facilities

The below areas should be reviewed by the NRC at each of the active DG vendors (Alco, Colt, Cooper, Morrison-Knudsen, and Stewart & Stevenson)*. In reviewing these areas the inspection should concentrate on diesel auxiliary system components. The areas to be reviewed in order of estimated priority are:

1. Failure reports and corrective action.
2. Design Change Control and modifications, design improvements vs. backfit questions.
3. Spare parts systems and hardware.
4. Part 21 evaluation system.
5. Followup on previously identified problems.
6. Procurement and QA for spare parts.
7. Ongoing testing.
8. "No charge" accounts.
9. Torquing requirements.
10. Service information to customers

In each area, if significant problems are identified, the root causes should be identified and the QA system reviewed to determine why it did not prevent/correct the problem.

5.2 Nuclear Power Plants (NPPs)

The DG areas below should be reviewed at selected nuclear power plants with different DGs, as a pilot program. The results of this pilot program would determine its productivity and the need to continue it at the remaining NPPs. As with the DG vendor inspections, the reviews of the below areas conducted at the NPPs should concentrate on the auxiliary system components. The areas to be reviewed in order of estimated priority are:

1. Failures, failure analyses, and corrective actions.
2. Maintenance.
3. Design Change Control for modifications to DGs.

*TDI clearly also needs inspection attention, but the inspection areas are different from those listed here.

4. Spare parts system and procurement for DGs.
5. Training.
6. Observe DCs in operation.
7. Receipt of design information, maintenance and operational recommendations, and other service data from vendors (especially for GM DGs).
8. Review procedures to limit cold fast starts.
9. Use of DG vendor and subvendors for various services is properly handled.
10. DG reliability records and calculations.
11. Verify that the utility has reviewed and implemented, as appropriate, recommendations of NUREG/CR-0660 and NSAC-79.
12. Torquing requirements and implementation on DGs.

5.3 General Recommendations

The following additional items were developed as recommendations during the reviews of this project. More detail is given in the referenced sections of this report.

1. Inspect Woodward Governor Co. (WGC) due to large number of failures (Section 2.1.3).
2. Review and re-evaluate the NRC position with respect to WGC's compliance with Appendix B and Part 21, and the use of Woodward Governors by the majority of nuclear DGs (Section 2.2.3).
3. Establish a requirement for utilities to provide the pertinent vendor with failure reports (Section 2.2.3).
4. Review ASME code breakdown of DG components (Section 2.2.3).
5. Review of the situation where utilities are buying spare parts and services from formerly (but no longer) nuclear grade vendors (Section 3.2).

6. INSPECTION PLANS

6.1 Plan for Inspection of DG Vendors

A. Objective

To review and evaluate the Diesel Generator Vendors and determine if their continuing performance is adequate in light of their ongoing activities to supply safety-related parts and services to Nuclear Power Plants.

B. Details

1. The inspection of the below items should focus on DG auxiliary systems as follows: Fuel Injection Systems, Turbocharger, Starting System, Speed/Load Control, Cooling Water, Lube Oil, Fuel Oil, Control and Monitoring Systems, and Generator.

2. Using the LER, 50.55e, and Part 21 systems computer printout and the VITS printout select 5 recent failures (within 2 years) for followup at the vendor. When at the vendor, select an additional 2 failures from his internal system. Evaluate the vendor response to these failures for proper failure analysis, corrective action, notification of affected DG owners, Part 21 evaluation and documentation.

3. Review the vendors design change control/modification system. Determine how engineering decides if a modification is to apply to the entire DG line or just future models. Is it adequate? For those that must apply to engines already shipped, verify how customers are notified. For those that are only design improvements at customer option, how are NPPs notified and given opportunity to install. Review several changes for proper implementation (Reference I.E. Inspection Procedure (I.P.) #37700).

4. Spare Parts systems and hardware: Review how spare parts are supplied to NPPs, both those fabricated at the DG vendor and those purchased from subvendors. Verify adequate QA and Part 21 handling and pass on to subvendor. Verify ASME code specified where applicable. Tour spare storage, note quality of parts and storage (Reference IE I.P. #38701B).

5. Part 21 Evaluation System: Using the examples from item 2 above, ensure that the system evaluates all failures. Also determine what systems the vendor has for internal nonconformance and failure reporting. See that there are provisions for escalating these into the Part 21 system. Have they been used properly? Has the DG vendor picked up the Part 21 responsibility from subvendors such as Woodward Governor Co.? Are evaluations and time frames adequate. Do field failures get into systems? (Reference IE I.P. #36100B)

6. Ensure adequate response and followup to items identified on previous NRC inspections. Verify that the issue of concern was understood and properly addressed to correct any root causes of problems.

7. For any ongoing or recent testing, perform a test procedure review, test witnessing, and/or test results evaluation. IE I.P.s 70300, 70312, and 70323B give guidance, but are most likely much too detailed to be followed step by step at a vendor.

8. Review vendor no-charge accounts for field problems to determine which internal division is responsible and to see where problems may be. Select three problems identified here and perform a review similar to that done in 2 above.

9. Torquing: Review vendor torquing specifications to ensure they are appropriately detailed and transmitted to utilities. Ensure that actual torquing was performed and is documented. Ensure calibrated torquing equipment was used.

10. Ensure that the vendor's DG service information is comprehensive, understandable, and properly transmitted to NPPs. Include a review of maintenance and operational type information.

6.2 Plan for Inspection of DGs at NPPs

A. Objective

To review and evaluate Diesel Generator design operation, and maintenance at NPPs to ensure that the DGs will be available when needed to power safety systems.

B. Details

1. The inspection of the below items should focus on DG auxiliary systems as follows: Fuel Injection System, Turbocharger, Starting System, Speed/Load Control, Cooling Water, Lube Oil, Fuel Oil, Control and Monitoring Systems, and Generator.

2. Using the LER, 50.55e, and Part 21 systems computer printout and select 3 recent failures (within 2 years) for followup at the NPP. When at the plant select an additional 2 failures from the internal systems. Evaluate the licensee's response to these failures for proper failure analysis, corrective action, notification of vendor, Part 21 evaluation and documentation.

3. Maintenance: Refer to IE I.P.s #62700 and 62702, as they apply to DG maintenance. Additionally, does the NPP have and have they implemented the DG vendor's maintenance recommendations (especially those recommendations unique to nuclear service DGs such as Colt's described in NSAC-79)? Are maintenance personnel specially trained on DGs? Is failure information fed back into maintenance program? Has the NPP implemented recommendations of various studies referenced in Section 4 above.

4. Design Change Control: Select two DG modifications and verify properly implemented. Utilizing information from DG vendor inspection on modifications recommended, verify that NPP is receiving all pertinent information in this area from the vendor. (Reference IE I.P. 37700)

5. Spare Parts and Procurement: Review how spare parts and services are purchased and parts stored, both from DG vendor and direct from subvendor. Verify adequate Part 21 and QA, particularly when vendors are only supplying commercial grade parts and services (e.g., Woodward Governor and Stewart and Stevenson). Verify ASME code specified where appropriate. Tour spare parts storage area. (Reference IE I.P. 38701B)

6. Training: Ensure appropriate DG specific training given to maintenance, operations, QA, and management personnel. Are there adequate documents to describe DG operation onsite (both main engine and auxiliary systems)? (Reference IE I.P. #41700)

7. Observe DGs in operation. Ensure they run smoothly and are operated per procedure. Look for abnormal vibration and leaks (air, fuel oil, or lube oil). Check readings within specified limits. Are limits per DG vendor recommendations (are recommendations clearly specified?)? Is air quality in DG room satisfactory without excessive dust? Are control cabinets properly gasketed? Are instruments calibrated? Is trending of operating data preformed to detect degradation early?

8. Is NPP receiving all appropriate service information from vendor: design, maintenance, operational, etc. This is especially important for General Motors DG owners (verify they receive "Power Pointers" from GM).

9. Review site practices to limit DG cold fast starts.

10. Reliability records and calculations: Check logs, procedures, and calculations versus Regulatory Guide 1.108 criteria.

11. Ensure that pertinent studies on DG performance have been reviewed and recommendations implemented as appropriate (e.g., NUREG/CR-0660 and NSAC-79).

12. Torquing: Ensure plant has adequate specifications for all torquing. Ensure it is documented and done with calibrated equipment. Observe re-torquing if in progress.

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An evaluation of standby diesel generator performance at nuclear power plants between 1980 and 1983. All diesel generator vendors except Transamerica Delaval were evaluated. Material reviewed included failure data, inspection reports and previous studies by others. Charts and tables of data including maufacturer versus site location.

Conclusion is that diesel generator performance and reliability is reasonably good, when TDI experience is factored out. In addition, total loss of offsite power events are decreasing, thus increased inspection activity at diesel generator manufacturers is not required.

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